Development of Energy-Water Nexus State-level Hybrid Sankey Diagrams for 2010

Lawrence Livermore National Laboratory

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Acronyms

AER	EIA's Annual Energy Review
BGD	Billion Gallons per day
BTU	British Thermal Unit
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
EPSA	DOE Office of Energy Policy and Systems Analysis
EIA	Energy Information Administration
EOR	Enhanced oil recovery
FRIS	(USDA) Farm and Ranch Irrigation Survey
MGD	Million Gallons per day
NASS	(USDA) National Agricultural Statistics Service
NETL	National Energy Technology Laboratory
SEDS	(EIA) State Energy Data System
SSDA	State Sankey Diagram Analysis
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

1 Introduction

Sankey diagrams can be used to frame important discussions around energy and material resources, use and disposition. With rapid changes in the energy sector at the national scale, severe water constraints at the state level, and a growing awareness of the interconnectedness of energy and water, there is growing demand for information products that concisely depict energy and water for policymakers. (DOE. 2015a, DOE. 2015b, California. 2015, DOE. 2014). Policy action intended to advance the security, affordability and sustainability of energy and water can occur at the federal, regional, state and local level. States are often at the vanguard of responsive and impactful energy and water policy. Coincidentally, much of the data necessary to visualize energy and water flows at the state level, and thus to inform policymakers, is collected at state-level granularity. Energy-water sankey diagrams provide policymakers, state planners, educators, governmental agencies, and nongovernmental organizations with detailed analysis to make informed decisions and plan for technologies and policies.

Lawrence Livermore National Laboratory (LLNL) worked with DOE's Office of Energy Policy and Systems Analysis (EPSA) and the National Energy Technology Laboratory (NETL), to produce this atlas of hybrid energy/water Sankey diagrams for each of the U.S. states. These diagrams depict energy use and water flow in each state during the year 2010, the latest year for which comprehensive data is available.

The methodology and assumptions for the state-level analysis includes a fusion of diverse sources of data and follows the basic methodology used by EPSA to create a national energy/water diagram. (DOE. 2014). Where appropriate, more detail has been added at the state level. Appendix A describes in detail the calculations that were used.

Chapter 2 presents a brief review of the most important interactions between energy and water, and identifies specific U.S. states where these interactions are strongest. Chapter 3 contains the state energy-water Sankey diagrams. Chapter 4 includes state rankings of some important energy-water statistics. The appendices to this report describe the extensive data fusion and analysis process that was required to generate the diagrams. They also describe the stakeholder engagement process through which these diagrams were reviewed and describe the existing pace of data releases that could enable this analysis to be updated in the future.

2 The Energy-Water Nexus

2.1 A brief review of the intersections between energy and water

As described in the Water Energy Nexus Report (DOE. 2014.), there are several major interactions between energy and water supplies, infrastructures and disposition across the economy. A brief description of both major and minor energy and water interactions follows. These descriptions are not intended to be comprehensive technology assessments; rather they serve to highlight the large installed base of water-consuming (and producing) energy applications and energy-consuming water applications.

Major uses of Water in Energy Applications

- **Thermoelectric Cooling**: Water is used as a heat sink for energy rejected during the process of turning thermal fuels (eg. coal, natural gas, geothermal and nuclear) into electricity. Most power plant cooling systems can be classified as either once-through or recirculating. In most once-through systems, water is withdrawn from a body of surface water. The temperature of the water is elevated by 5 - 15K, usually via heat transfer in the power plant's condenser, before the water is discharged back to the surface. In contrast, most recirculating systems depend on the large latent heat of vaporization of water to dissipate the energy load. In these systems, far smaller quantities of water are withdrawn from surface and/or groundwater sources, but a much larger share of the withdrawn water is consumed via evaporation in cooling towers.
- **Hydropower:** The gravitational potential energy of water which fell as precipitation on elevated land is converted to electricity in hydroelectric turbines. Water withdrawal is not estimated for this application because impoundment of water and subsequent release downstream of dams and turbines is not consistently considered a "withdrawal". Estimates have been made for the water consumption (mostly evaporation) associated with the operation of hydropower reservoirs; however those quantities are highly uncertain, and variable with annual and seasonal weather. This analysis does not consider the withdrawal and consumption associated with hydropower. Nonetheless, hydropower represents a major component of the Energy-Water Nexus, and hydropower output is subject to natural and human-caused variations in water supply.
- **Oil and Natural Gas Extraction:** Oil and natural gas operations can both produce and consume water. When oil and natural gas are extracted from the subsurface, water is often extracted along with them. This "produced water" may contain organic compounds and salts which can potentially be treated before being discharged into subsurface water. Produced water must be treated and/or re-injected into the subsurface. Water is also injected into some oil and natural gas wells, either for secondary flooding and enhanced recovery or at high pressure for hydraulic fracturing.
- **Coal Production:** Water is used extensively in the mining industry, and in the case of coal mining (extraction of an energy resource), water is used for washing and dust control in ongoing operations. Water used in coal mining may be consumed or discharged to surface water supplies. Coal-associated water can also seep out of the mine and must be pumped, treated and injected or discharged. Disposal of coal-mining wastewater through subsurface injection is not included in this analysis.
- **Biomass Production:** In regions of the country where there is inadequate rainfall during the growing season, irrigation is used to support the growth of biomass feedstocks (chiefly corn) for biofuels production. This "upstream" use of water to produce an energy feedstock can be the dominant water input into some biofuel production pathways.

- **Fuel Refining:** Water is an input into the industrial processes that produce both petroleum-based fuels and biofuels. Gasoline, diesel and kerosene (jet fuel) are produced in oil refineries, which withdraw and consume water as a process input and for cooling purposes. Similarly, ethanol is produced in dry mills, which also use water as a process input and as a cooling medium.

Major uses of Energy in Water Applications

- **Water Treatment and Distribution:** Withdrawal and treatment of water for potable use by municipal water suppliers requires energy input. Many water treatment processes are pressure (or gravity) driven (i.e. water flowing through filter beds or impurities settling out of water), so most of the energy consumed in water treatment is in the form of electricity used to drive pumps. Similarly, the energy used to withdraw water from surface and subsurface sources, and the energy used to by distribution systems, is consumed in pumping.
- **Wastewater Treatment:** The major energy-consuming processes used to remediate municipal wastewater (sewage) for release back into the environment are also primarily pressure- or gravity-driven. These processes include aeration, sedimentation, decanting and dewatering. The wastewater treatment industry is also a major consumer of electricity. Processes such as anaerobic digestion can recover some of the energy in the organic component of sewage as methane which can be burned for heat, exported to for sale or converted to electricity for internal use or grid export. This analysis considers only the net consumption of electricity in wastewater treatment.
    - **Water Recycling:** The practice of treating municipal wastewater to a quality where it can be directly or indirectly used to offset supply of withdrawn water is small and growing. Water recycling is more energy intensive than traditional wastewater treatment, but may be competitive on a systems level with traditional water supply and wastewater management, particularly in water-strained areas. Although this 2010-year analysis of the Energy Water Nexus does not consider water recycling, the topic may be appropriate for future updates.
- **Agricultural Water Supply:** Because waters for irrigation, livestock and aquaculture do not require the same level of treatment as potable water, the energy intensity of agricultural water use (per unit water) is lower than that of municipal water supply. Nonetheless, pumping for withdrawal and pressurization of water in the agriculture sector (the largest sector in terms of water consumption) requires significant quantities of electricity.
- **Conveyance:** In some regions, particularly in the arid Western United States, water is conveyed over long distances from surface supplies to agricultural, industrial and municipal users. The energy required to drive the pumps that power these conveyance systems is almost exclusively electric. In this analysis, conveyance energy is apportioned to the end user (largely municipal and agricultural users) and lumped in with the energy of withdrawal and treatment.

2.2 What to look for in the diagrams

The Energy-Water Sankey Diagrams are a tool for technologists, policymakers and educators to explore the structure of energy and water systems at the state level and the interactions between these two infrastructures.

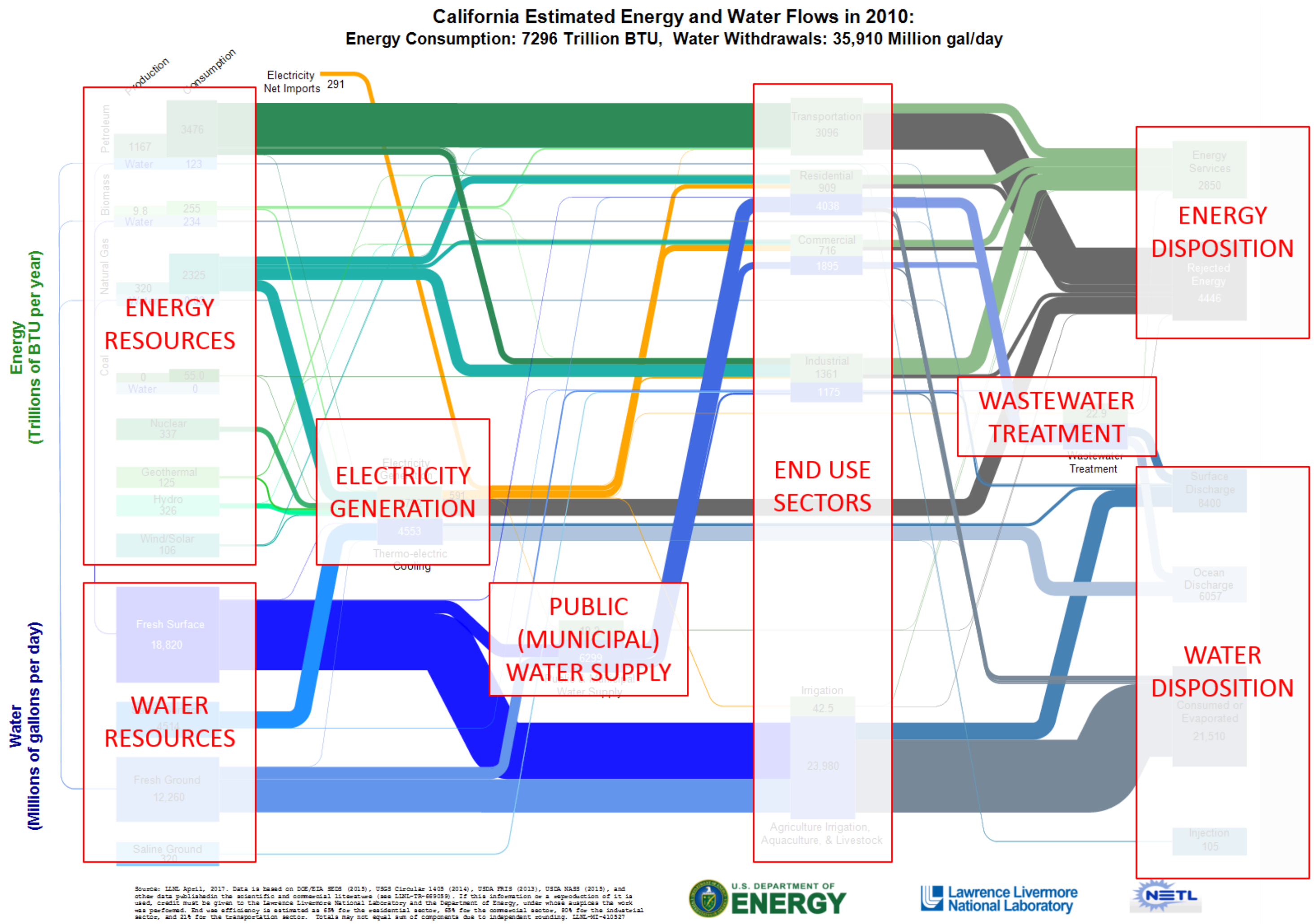


Figure 2-1 – Snapshot of energy flow chart and general location of energy and water categories. Energy and water generally "flows" from left to right.Some water resources also flow up to energy resources (petroleum, biomass, natural gas, and coal)

Energy Resources

The upper left portion of the diagram contains boxes representing the energy resources used by each state. A snapshot is shown in figure 2-2. For the resources whose production and trade are tracked by EIA (Petroleum, Biomass, Natural Gas and Coal), both the production and net in-state consumption amounts are shown. The height of the boxes representing net consumption are proportional in size to the quantity consumed, down to a de minimis dictated by legibility of the labels. The heights of boxes representing production are not proportional to the quantity of resource produced; rather, they are sized to denote whether the state is a net producer or consumer of a given material. Proportional sizing of these production boxes would have rendered illegible the consumption flows for the states that are large net producers. Water withdrawn for the production of petroleum, biomass, natural gas, and coal is depicted below the production and consumption boxes.

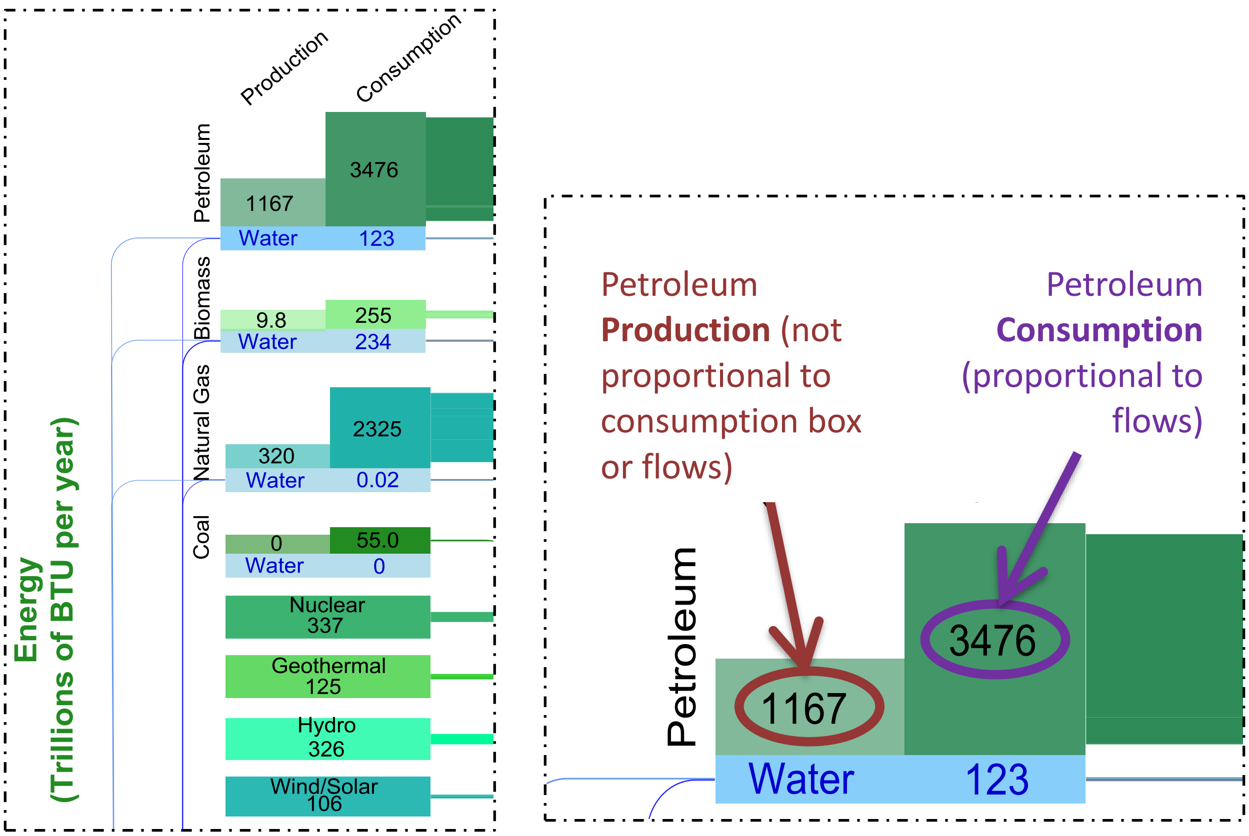


Figure 2-2 – Snapshot of energy sources.

Petroleum, biomass, natural gas, and coal resources show both the production and net in-state consumption as tracked by the EIA. The consumption is proportional to the flow out of the right side of the consumption box. The production is not proportional to flows or consumption due to page size restrictions. The production boxes do demonstrate whether the state is a net producer of a resource (when production box height is larger than consumption), or a net consumer (when consumption box height is larger than production as shown for CA).

For the following resources, State Energy Data System (SEDS) uses the consumption estimate to represent production: nuclear, geothermal, hydropower, wind and solar.

The diversity of a state's energy supply can be qualitatively evaluated by examining the relative thicknesses of the lines radiating from the right side of the energy resource boxes. For example, CA consumes more petroleum and natural gas than other resources as shown by the line thicknesses in figure 2-2.

Water withdrawn for use in the production of oil, natural gas, coal and dedicated biomass energy crops is shown flowing from the left-hand side of the water resources (see figure 2-2 and section below), upwards and into the lower-left of these “water” labeled energy resource production boxes.

For the oil and natural gas resources, water “in-flows” (left of the box, see figure 2-2) represent water withdrawals: water withdrawn for primary recovery, secondary flooding, enhanced oil recovery and hydraulic fracturing. The water “out-flows” for oil and natural gas represent returns to the environment, such as produced water being returned to the surface or injected for disposal. The Sankey diagrams do not depict gross consumption (the fraction of withdrawals that remains in the formations) although estimates of consumption have been calculated. Most states have a negative net consumption due to net production being larger than net consumption. Therefore, neither gross nor net consumption are shown, and the oil and natural gas water boxes appear non-conservative (inflows do not equal outflows). The oil and natural gas sector appears as both a water resource, and a water user. Produced water treatment in the oil and natural gas sector is not shown. Energy used in produced water treatment is assumed to be part of industrial energy use, and could not be calculated from the data available.

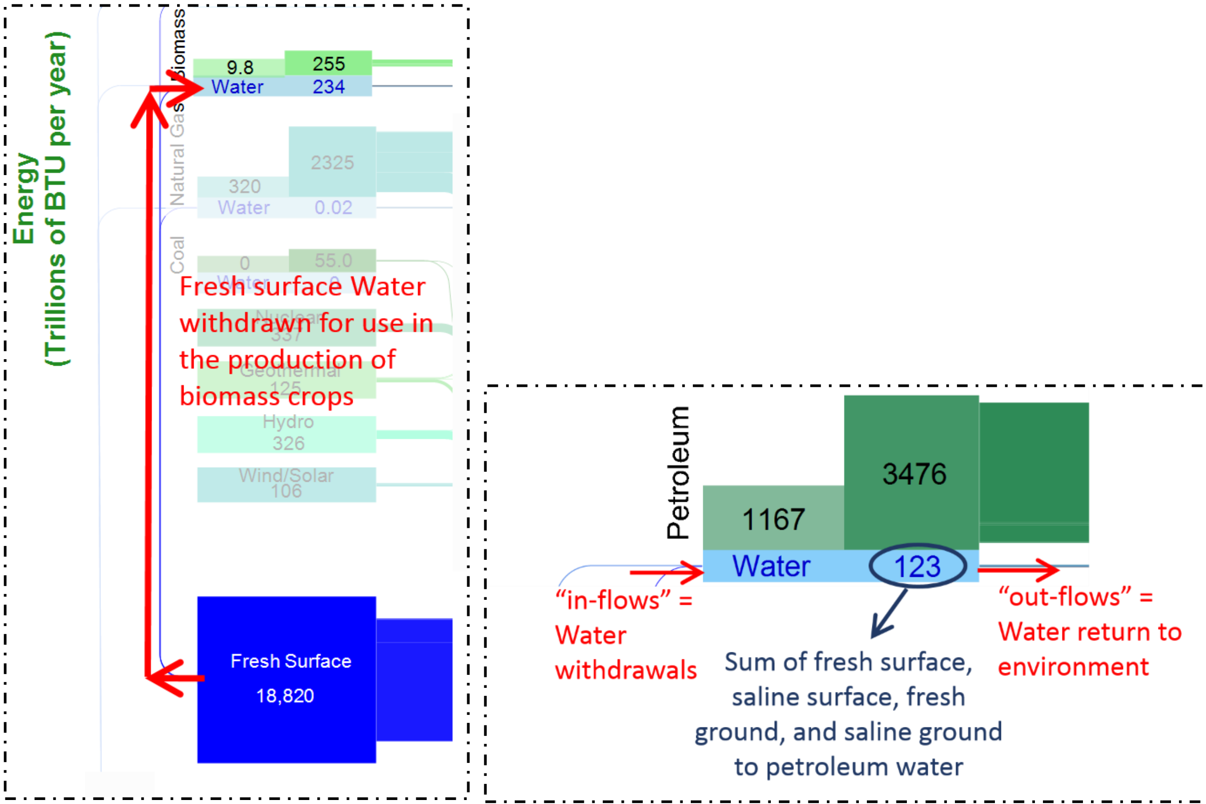


Figure 2-3 – Water used for energy production

(Left) Water withdrawn for use in the production of biomass crops flows *from* the left-hand side of the fresh surface (water resources) box, upwards and *into* the left-hand side of the "water" box representing water used to produce biomass. (Right) Water returning to the environment is represented by the "out-flows" from the right-side of energy resource related water box.

Water Resources

The lower left portion of the diagram contains boxes representing the water resources accessed in the state, as shown in figure 2-4. As noted above, water used in the extraction of fossil fuels and biomass feedstocks is shown to the left of these boxes. Flows of water out of the right-hand side of the water resource boxes represents water withdrawals from each of fresh surface water (typically lakes, rivers), fresh groundwater (typically shallow aquifers), saline surface water (typically oceans) and saline groundwater (brackish and/or brine aquifers). The relationship between water resources in a given state (for example, isolation of multiple surface water resource from each other in different hydrologic basins, or the connectivity between shallow groundwater aquifers and surface water bodies) is not addressed in this report.

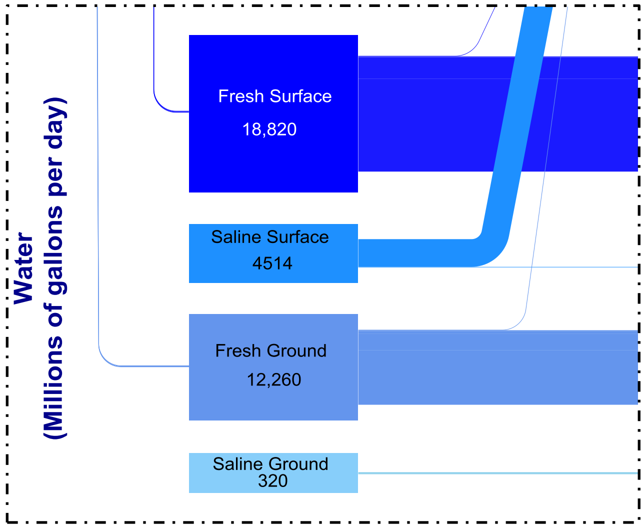


Figure 2-4 –Snapshot of water resources.

Withdrawals can be from fresh surface, saline surface, fresh ground, or saline ground sources.

Patterns of water withdrawal vary widely from state-to-state, with the largest sources of variation driven by the quantities surface water (fresh and/or saline) used for thermoelectric cooling and the quantities of fresh water (surface or ground) used for irrigation.

Electricity Generation

Electricity generation is a key component of energy transformation and distribution within each state, and is often among the largest consumers of energy resources. It is also often the largest component of water withdrawal for energy purposes (thermoelectric cooling). Electricity generation is depicted near the left-hand side of the diagram, about halfway between the top and bottom. A snapshot is shown in figure 2-5. States with a high proportion of once-through cooled power plants are marked by electricity generation (green) and thermoelectric cooling (blue) boxes of approximately the same height. States whose generation box appears much taller than the cooling box have adopted recirculating cooling technologies. The Electricity Generation "box" in this analysis includes electric generators whose primary purpose is to produce electricity for sale, and excludes commercially and industrially owned generators that primarily produce power for self-consumption.

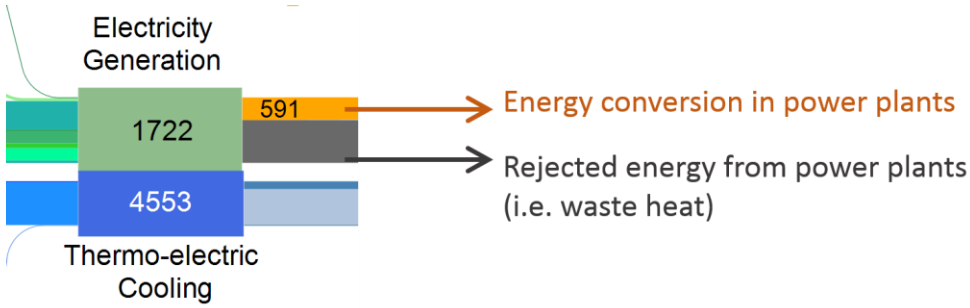


Figure 2-5 –Snapshot of electricity generation.

Public (Municipal) Water Supply

Below and to the right of Electricity Generation is a box representing the withdrawal, treatment and distribution of potable water. Not only is water supply a critical link in the residential, commercial and industrial use of water, it is often the largest consumer of energy in the water sector. The diagrams clearly indicate the mixture of fresh surface and groundwater used for public supply. The energy intensity of public supply depends on the depth and quality of the water resource accessed. Energy intensity of public supply is discussed later in this report because it is not clearly visible due to the scale of the diagrams.

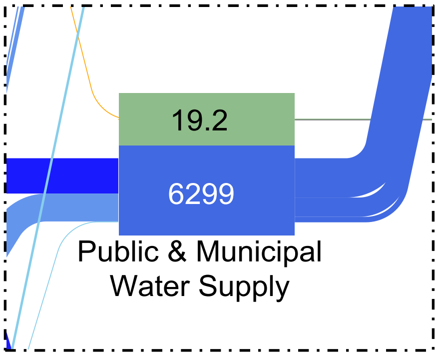


Figure 2-5 –Snapshot of electricity generation.

End Use Sectors (Transportation, Residential, Commercial, Industrial, Agricultural)

The main uses of energy and water across the economy are the end use sectors shown in figure 2-6 – transportation, residential, commercial, industrial, and agriculture (irrigation, aquaculture, and livestock).

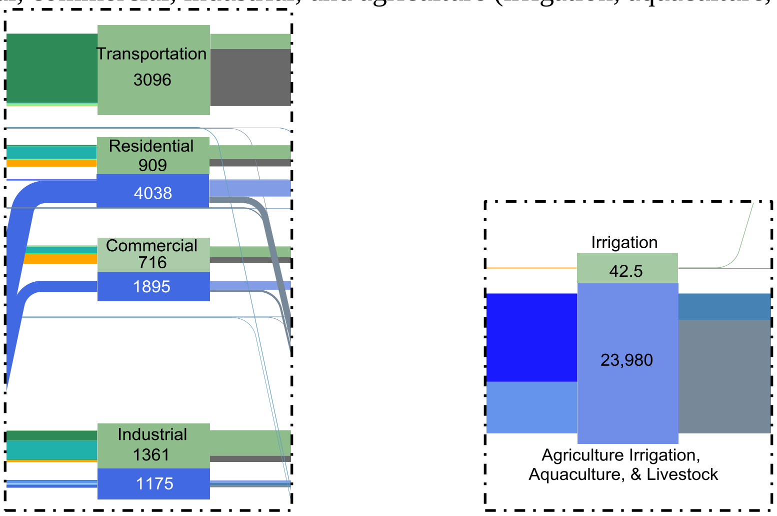


Figure 2-6 –Snapshot of end use sectors
transportation, residential, commercial, industrial, and agricultural.

Transportation end-use (top), sometimes the largest user of energy on a state-by-state basis, is generally independent of water infrastructure, even though the production of fuels for transportation are not. Exceptions to this statement (e.g. barge transport) are not analyzed here. The vast majority of transportation energy use is based on petroleum. It is important to remember that “embedded” water use in energy is depicted on the diagram as direct use of water in the production of those energy carriers.

The Residential and Commercial sectors represent the coincident uses of energy and water within and around the built environment. The residential sector includes indoor water and energy use as well as water used for landscape irrigation. The commercial sector includes energy and water use inside small, medium and large commercial buildings (offices, shops, hospitals, schools, etc.), as well as outdoor uses of energy and water such as municipal irrigation of parks and outdoor lighting of streets and signage. In general, energy and water consumption at the point of end-use in these sectors are independent of one another (see "embedded" discussion in the previous paragraph). Analysis of coupled use of water and energy in the buildings sectors (e.g. energy used for water heating, or water used in evaporative cooling systems) would have required significantly higher resolution on the diagram to depict and are not analyzed in detail. Electricity and natural gas supply the bulk of energy to these sectors, with electricity dedicated to a large number of end uses (lighting, appliances, communications, refrigeration, etc.), and natural gas largely supplying heating. Self-supplied energy (eg. rooftop solar) is a small and growing component of residential energy and is depicted because data is readily available in SEDS. In some states where natural gas infrastructure does not extend to all residential and commercial buildings, oil is used for heating. In urban and suburban areas, most water supplied to the residential sector comes from public supply, which, in turn, may derive water from fresh surface or groundwater resources. In many rural areas, residential water use is supplied from private groundwater wells. Because there is currently no data collected regarding self-supply for water use in the commercial sector, it is assumed that all commercial water is delivered from public supply.

The Industrial sector (near the middle of the diagram) represents a diverse mixture of water and energy uses. In some instances (e.g. petroleum refining), water and energy use are tightly coupled. In other instances (e.g. paper and textiles), water and energy are both process inputs, but their use is coincident, and interdependent only to the extent that supply and treatment of used water requires energy, and supply and rejection of energy requires water. At the level of aggregation in these diagrams, the coupling of energy and water use in industry is not explicitly depicted. The analysis includes an estimate of water used for fuels refining, which is reported in a separate table. The overall industrial intensity of a state's energy economy can be estimated by comparing the size of the inputs to the industry box with the size of the residential and commercial sectors. The overall water intensity of a state's industry is also clearly visible in the diagrams. Industries use a wide variety of energy inputs (chiefly oil, natural gas, biomass, coal and electricity), as well as a wide variety of publicly supplied and self-supplied water. Although water supply and wastewater treatment facilities may be considered "industrial," their energy use is explicitly excluded from the industrial sector on this diagram (it is accounted for in separate boxes). Furthermore, electricity for agricultural water supply (pumping) is excluded from the industrial sector in this analysis as it is accounted for elsewhere (see Appendix A.4.4). Also in this analysis, the water used in the mining industry (except for that used in coal, oil and natural gas extraction) is included in the total of industrial water use.

The agricultural sector, at the bottom of the diagram, includes irrigation for crops as well as water use for aquaculture and livestock. For the purposes of this water-energy analysis, energy use in the agricultural sector includes only the electricity associated with water use (pumping for supply and pressurization of irrigation water and livestock care). Additional use of energy in agriculture (fuel for farm equipment, lighting, heating and ventilation of animal care facilities, crop processing and drying, etc.) is excluded here, and included in industrial energy use. Because irrigation of crops is the largest user of water in agriculture, the diagrams clearly depict the states with the largest quantities of irrigation. States whose agricultural sectors require little irrigation (because of sufficient rainfall), and states with small agricultural sectors show very thin lines going to this area. Agriculture depends largely on fresh surface and groundwater, and this is clearly evident from the diagrams.

Wastewater Treatment

Just to the right of the end use sectors, there is a box that shows wastewater treatment. A snapshot is shown in figure 2-7. The residential, commercial and industrial sectors return a large fraction of the water that they use as degraded water to the environment. In most urban and suburban areas, wastewater is collected through networks of sewer pipes and treated at a centralized facility. Wastewater collection is usually gravity fed, and the treatment process is driven largely by pumping, mixing and other mechanical processes. These treatment plants, therefore, are a consumer of electricity, and the interaction of water management and energy consumption is clearly visible on the diagram. Opportunities to recover the energy available in wastewater, while beyond the scope of this report, are discussed in depth elsewhere (DOE. 2014, 0). Similarly, opportunities to recycle and/or reuse wastewater are not depicted.

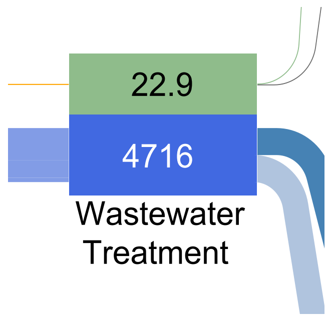


Figure 2-7 –Snapshot of wastewater treatment.

Energy Disposition

The upper right portion of the diagram depicts the split between energy that is successfully applied to end use and energy that is rejected to the environment. No energy transformation can be 100% efficient. For example, conversion of coal, natural gas, and nuclear energy in thermal power plants is, averaged over the existing fleet, about 35% efficient due to the fundamental thermodynamics governing the underlying technology. The remainder of the energy (on average 65% of the energy input) is rejected as waste heat to the environment. Most of this waste heat is often removed from power plants in cooling water, which drives the need for water for thermoelectric cooling. Electricity generation does not contribute directly to energy services because the useful result of electricity generation is consumed by the end use sectors. This analysis does not calculate the efficiency of different forms of electricity production, nor does it assume a single efficiency for all power plants. Rather, it uses the difference between total energy inputs to electricity and total electricity produced to calculate rejected energy (see Appendix A.3.1)

In the end use sectors, energy efficiency is estimated. In the transportation sector, energy services are calculated based on the mechanical work done to propel vehicles. All remaining energy is assumed to be rejected to the environment as heat transfer from vehicle cooling systems and/or energy remaining in vehicle exhaust. Efficiencies of the commercial, residential and industrial sectors are somewhat more difficult to calculate (LLNL. 2010a, LLNL. 2013, LLNL. 2010b) and are estimated to be 65%, 65%, and 80% respectively.

The energy used in the water treatment, agriculture and wastewater treatment sectors is also split into services and rejected energy. These sectors are largely dependent on pumping and other mechanical energy derived from electric motors. While calculation of the thermodynamic value of the services rendered is challenging, these sectors are assumed to be 65% efficient, which is a reasonable estimate of the conversion efficiency of electrical to hydraulic energy in water treatment and distribution systems.

The overall efficiency of a state's energy economy, as depicted in these diagrams, is dependent on its mix of energy end use, and does not vary greatly from state to state.

Water Disposition

The lower right portion of the diagram depicts the fate of all water that is withdrawn from surface and groundwater resources. A snapshot is shown in figure 2-7 Most water that is withdrawn is returned to surface waters (lakes and rivers) and some used water is discharged directly to oceans. These discharged waters are usually degraded in quality in some form (carrying more salts and/or organic matter than they did when they were withdrawn, or are discharged at higher temperature). In some cases, surface water quality can be maintained despite degraded water discharge by natural processes (cooling through natural evaporation, salinity reduction through dilution and organic matter destruction through oxidation). In other cases, however, surface water quality is often affected because these natural processes are not fast enough for the volume and quality of degraded water that is discharged. Large rates of water withdrawal can also diminish natural systems' capacity to dilute pollutants. Wastewater treatment, depicted on the diagrams as a step prior to some water discharge, uses engineered and intensified natural processes to improve water quality before discharge.

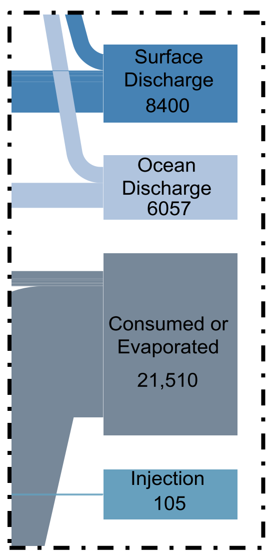


Figure 2-7 –Snapshot of water disposition.

Most of the water that is not discharged back to the surface is consumed. Water consumption most often takes the form of evaporation, and the two largest instances of evaporation depicted on these diagrams are thermoelectric cooling and agriculture. The residential and industrial sectors also evaporate significant fractions of their withdrawn waters, through outdoor irrigation and process cooling respectively. Evaporated water ends up in the atmosphere, and is eventually returned to surface or ocean waters through precipitation, usually far from where the consumptive use of water occurred. A fraction of withdrawn water is also consumed by incorporation into agricultural and industrial products via chemical transformations. Data on the consumptive use of water in the residential, commercial, industrial and agricultural sectors has not been collected or analyzed nationally with state-level disaggregation since 1995. Appendices A.4.2 through A.4.5 describe the assumptions used in the calculation of consumptive water use in these sectors.

Some highly impaired wastewaters are disposed of permanently in the subsurface via underground injection. While disposition of water in this manner is relatively small compared to most other forms of water disposition, it is becoming increasingly important to the oil and natural gas industries as unconventional resources are developed.

Patterns of water disposition vary from state-to-state depending largely on the state's access to oceans (treated wastewater from large coastal urban populations is discharged to the ocean), as well as its dependence on once-through thermoelectric cooling (this drives large discharge to surface and/or ocean waters) and irrigation for agriculture (which is a large consumer of water).

Notes on Scale

To optimize the legibility of the graphics, each state diagram is drawn at a different scale, chosen to maximize flow thicknesses while minimizing the need to move boxes. Hence, flow thicknesses should only be compared within a state, and not between states. For energy resources in some states, the box size ratio of production to consumption is not maintained due to graphic size limitations. The overall scale of energy and water use must be inferred by the reader from the totals and statistics printed on the diagram.

However, all diagrams use a consistent scaling between energy and water to maintain consistency in estimating analyzing energy-water nexus issues. For each unit thickness of line representing 1 Trillion BTU annual energy use, the same unit thickness line represents 4 Million gallons per day. Additionally, we include diagrams with varying energy to water ratios in Appendix F for some states (Alaska, Idaho and Montana), each of which has a significantly different water-to-energy usage ratio than the rest of the US. Alaska has a vastly different climate and economy than the contiguous U.S., while Idaho and Montana both have extraordinarily large acreage of irrigated crops in proportion to their population and other uses for energy and water.

3 50 State-Level Energy-Water Diagrams

The following table contains hyperlinks that jump to the associated Sankey diagram for each state:

Alabama	Hawaii	Massachusetts	New Mexico	South Dakota
Alaska	Idaho	Michigan	New York	Tennessee
Arizona	Illinois	Minnesota	North Carolina	Texas
Arkansas	Indiana	Mississippi	North Dakota	Utah
California	Iowa	Missouri	Ohio	Vermont
Colorado	Kansas	Montana	Oklahoma	Virginia
Connecticut	Kentucky	Nebraska	Oregon	Washington
Delaware	Louisiana	Nevada	Pennsylvania	West Virginia
Florida	Maine	New Hampshire	Rhode Island	Wisconsin
Georgia	Maryland	New Jersey	South Carolina	Wyoming

Figure 3-1 - Hybrid Energy-Water Sankey Diagram for Alabama

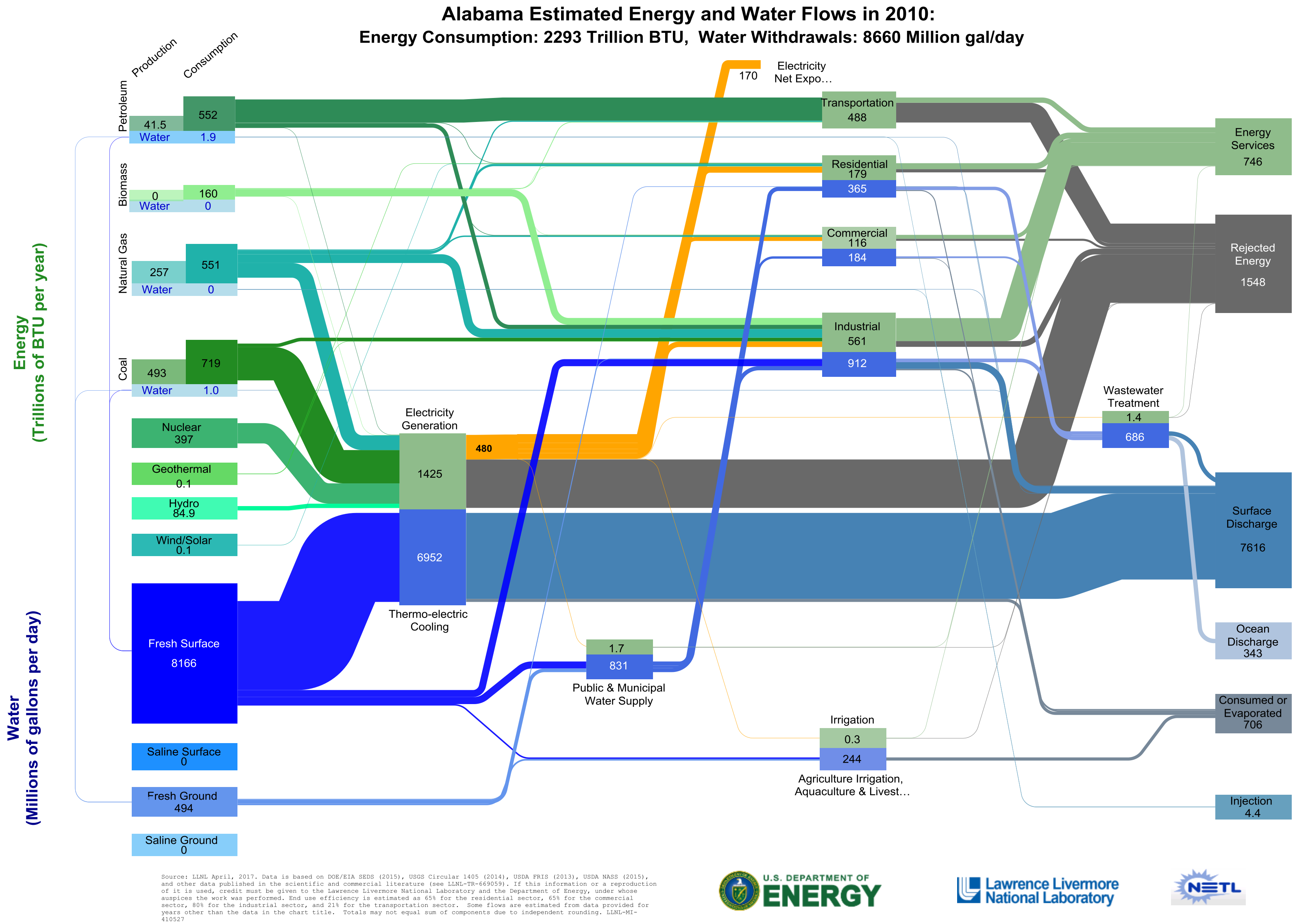


Figure 3-2 - Hybrid Energy-Water Sankey Diagram for Alaska

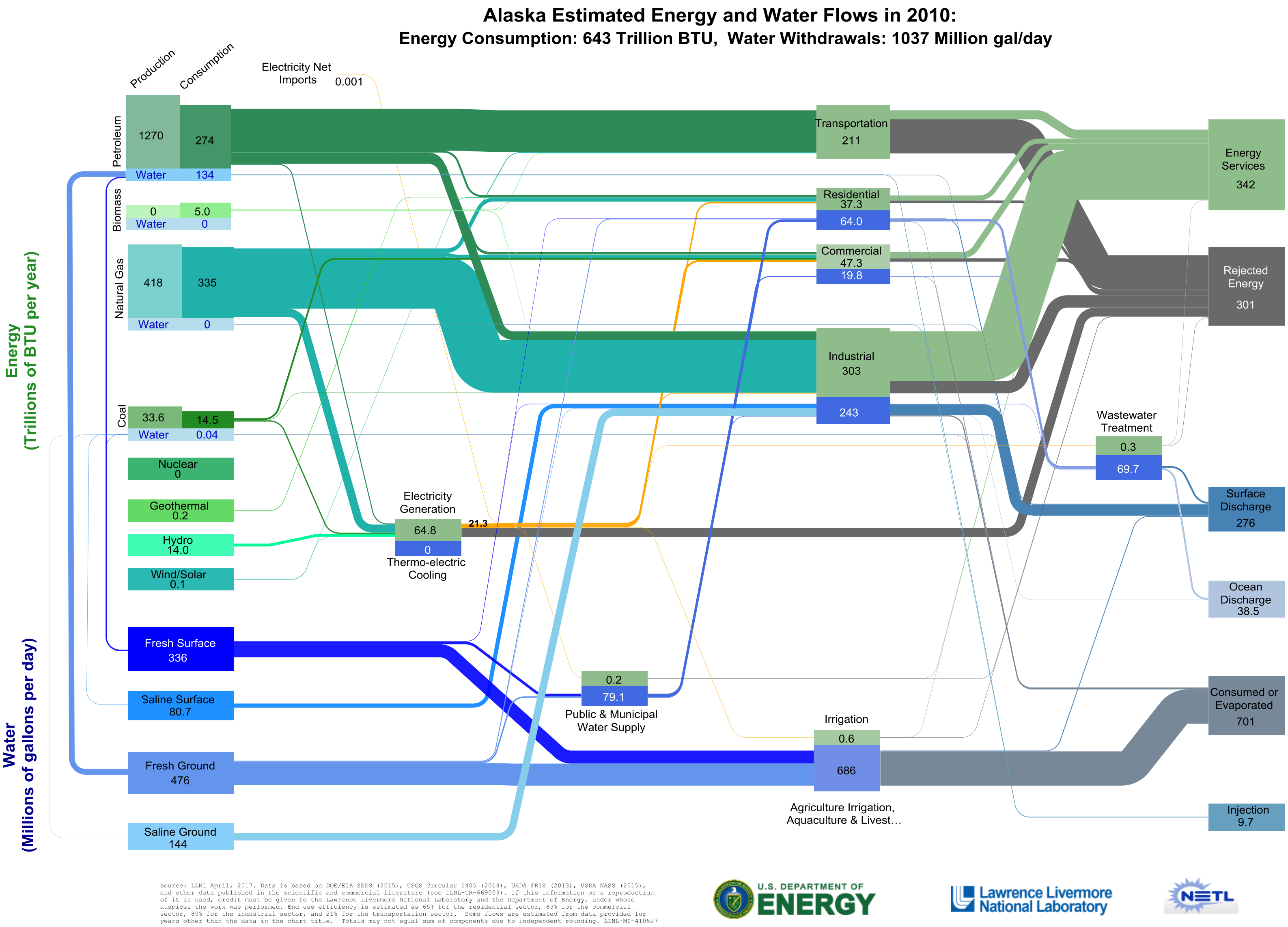


Figure 3-3 - Hybrid Energy-Water Sankey Diagram for Arizona

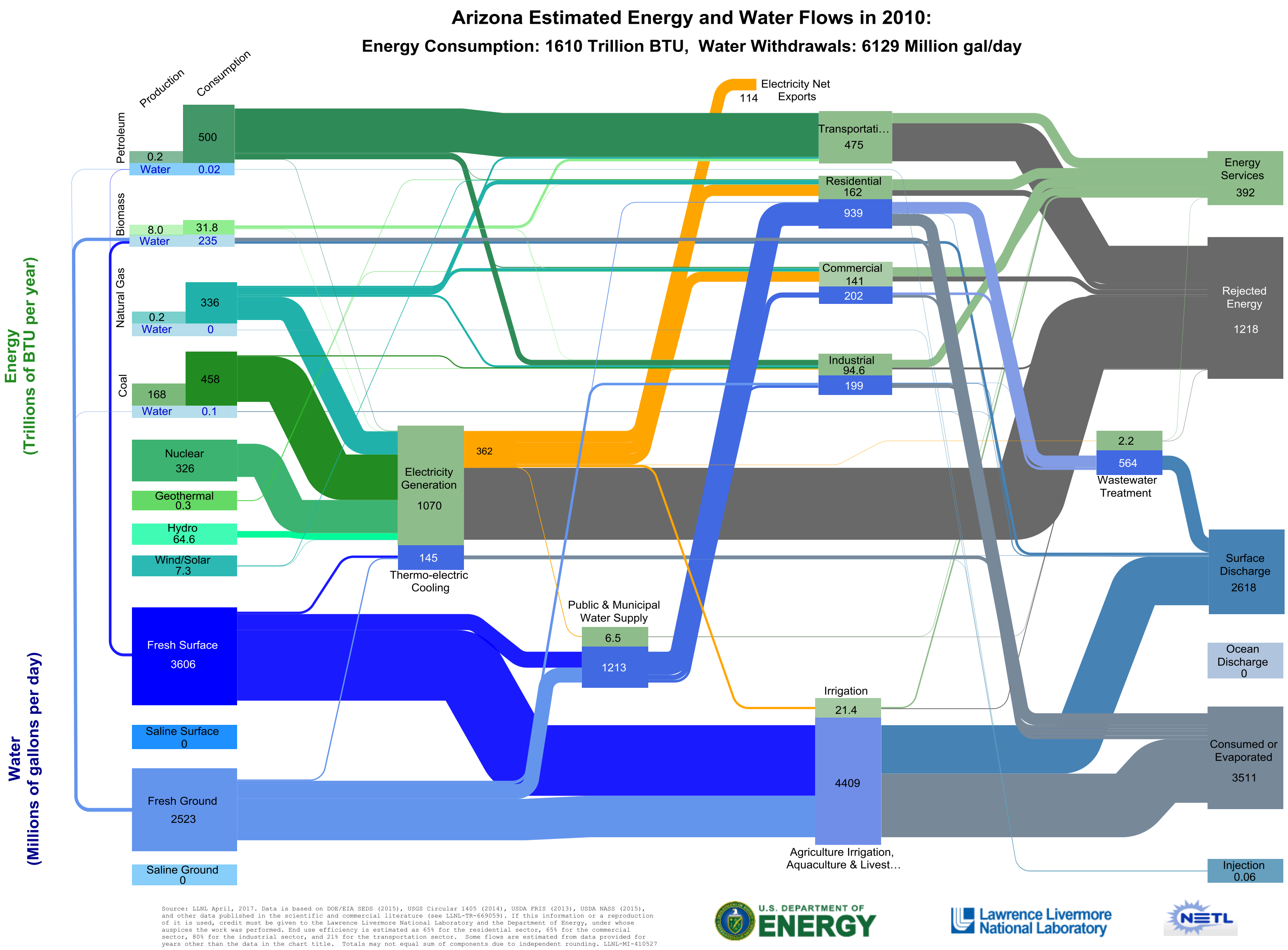


Figure 3-4 - Hybrid Energy-Water Sankey Diagram for Arkansas

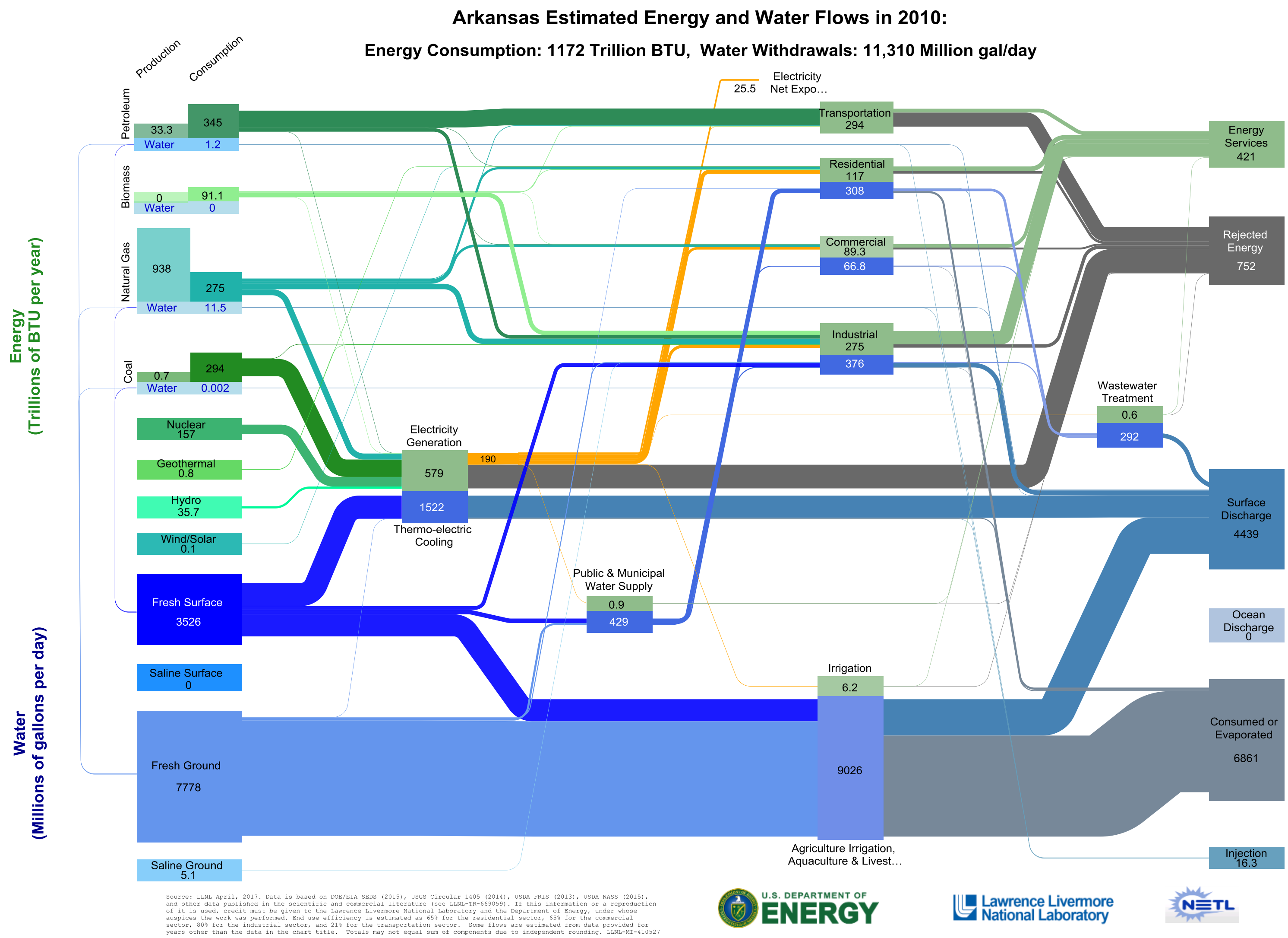


Figure 3-5 - Hybrid Energy-Water Sankey Diagram for California

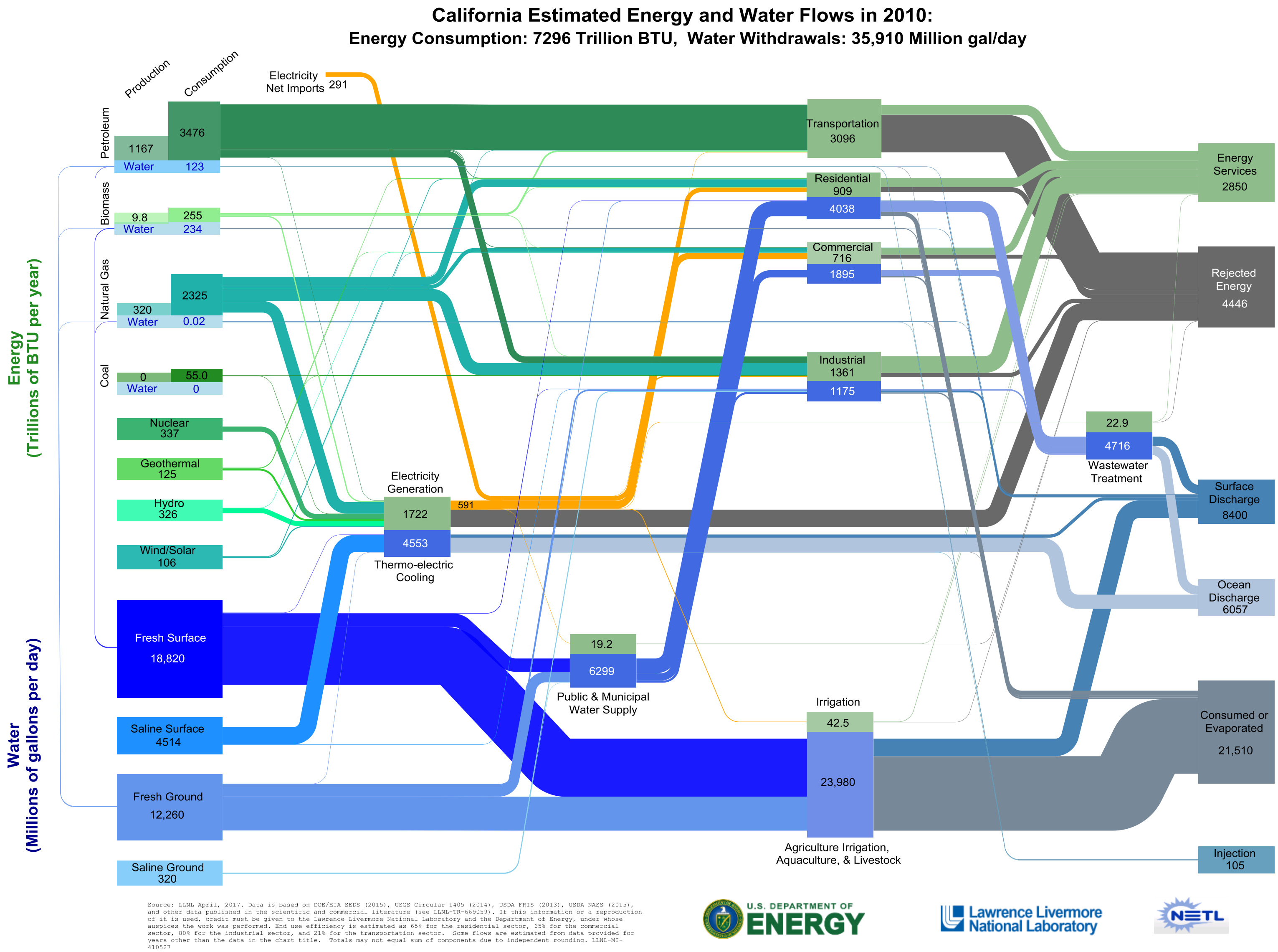


Figure 3-6 - Hybrid Energy-Water Sankey Diagram for Colorado

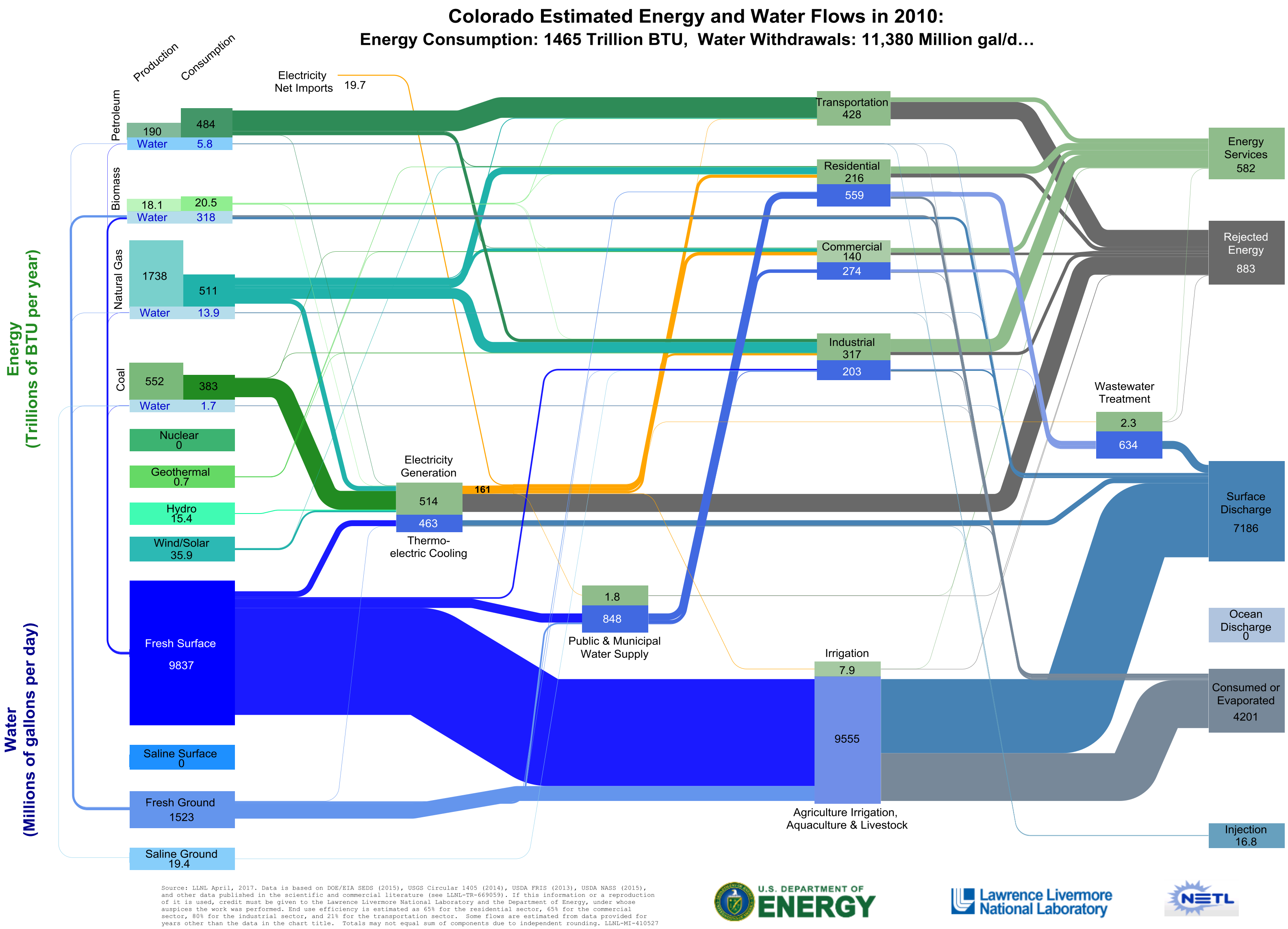


Figure 3-7 - Hybrid Energy-Water Sankey Diagram for Connecticut

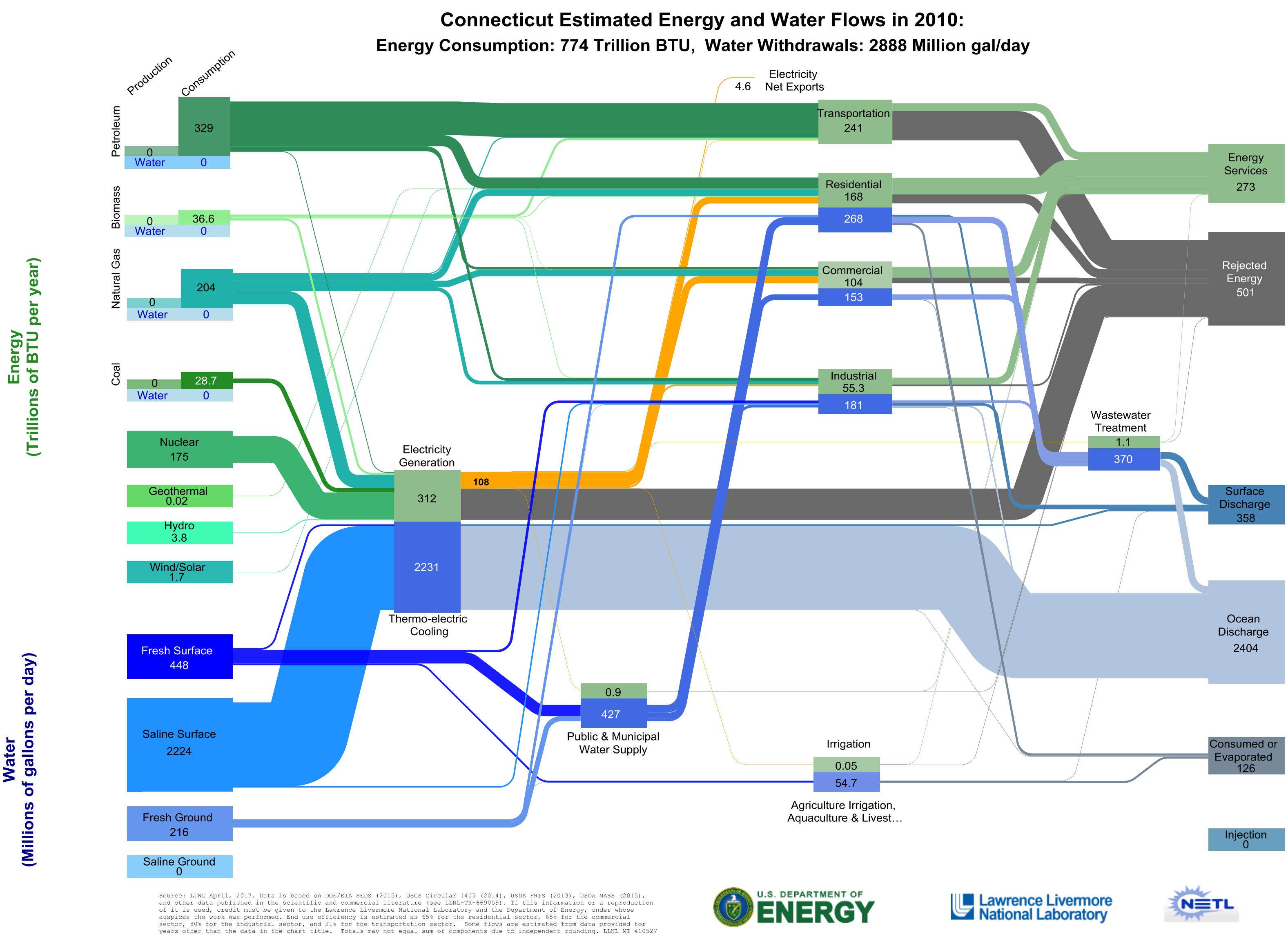


Figure 3-8 - Hybrid Energy-Water Sankey Diagram for Delaware

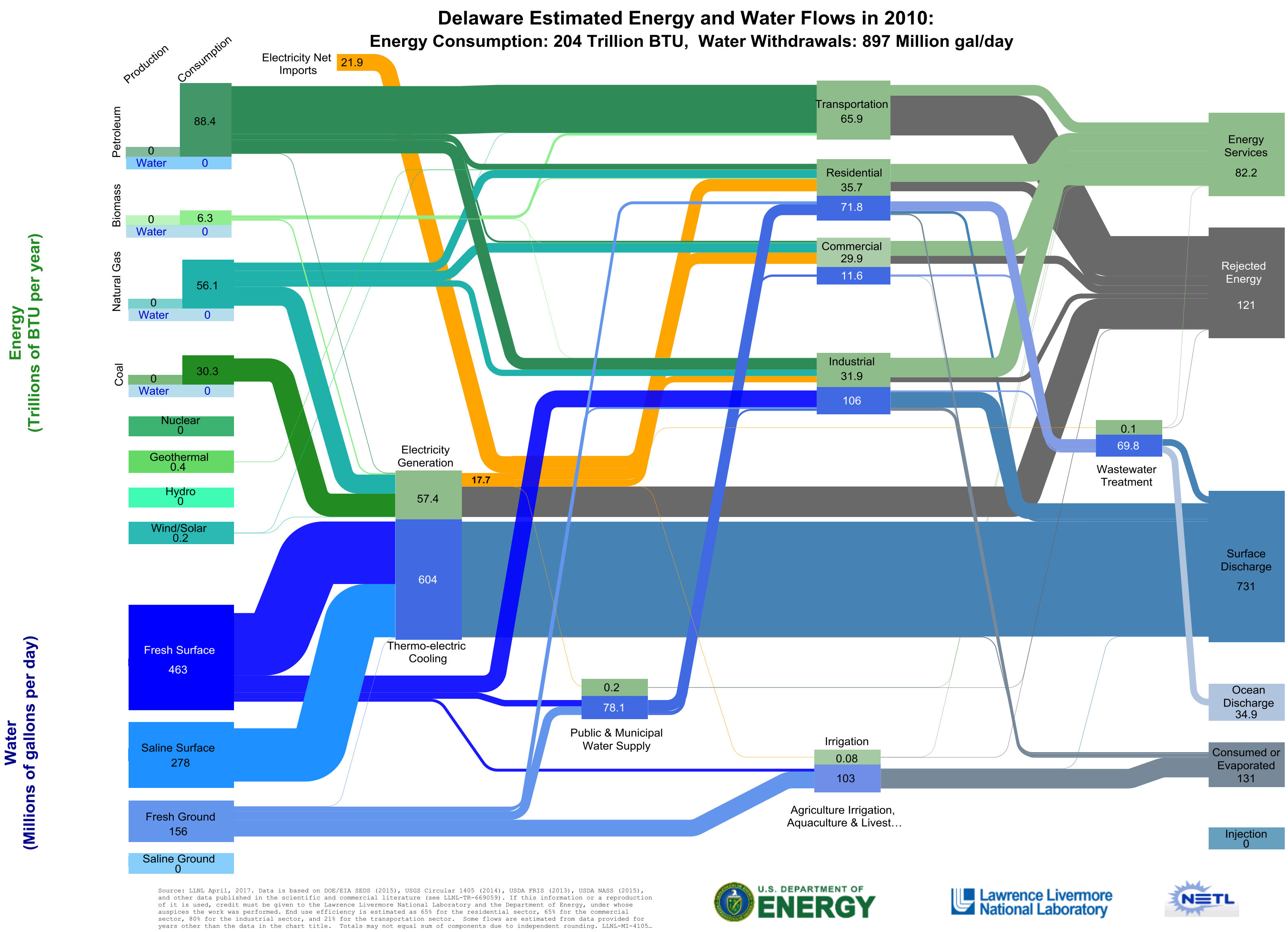


Figure 3-9 - Hybrid Energy-Water Sankey Diagram for Florida

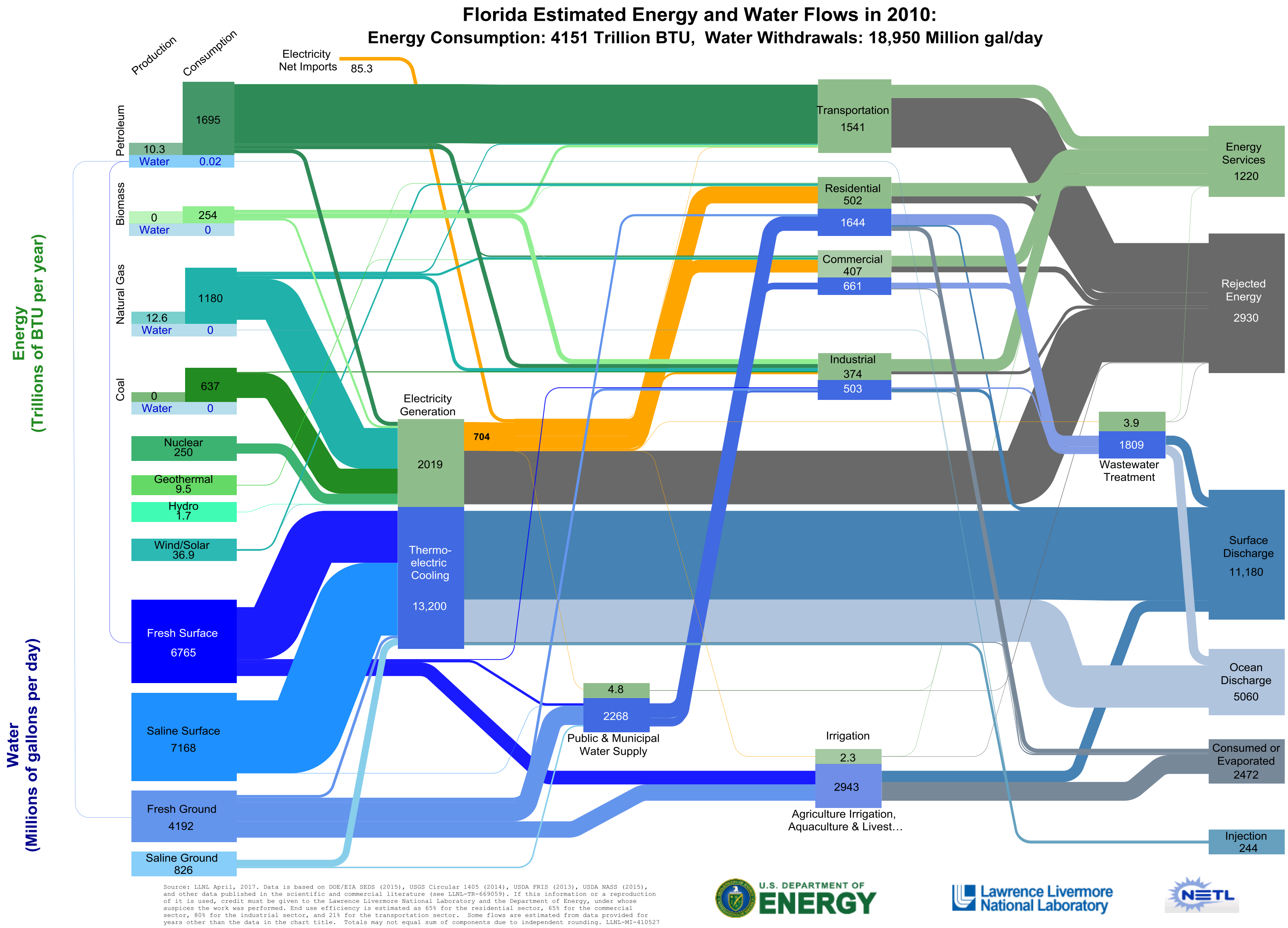


Figure 3-10 - Hybrid Energy-Water Sankey Diagram for Georgia

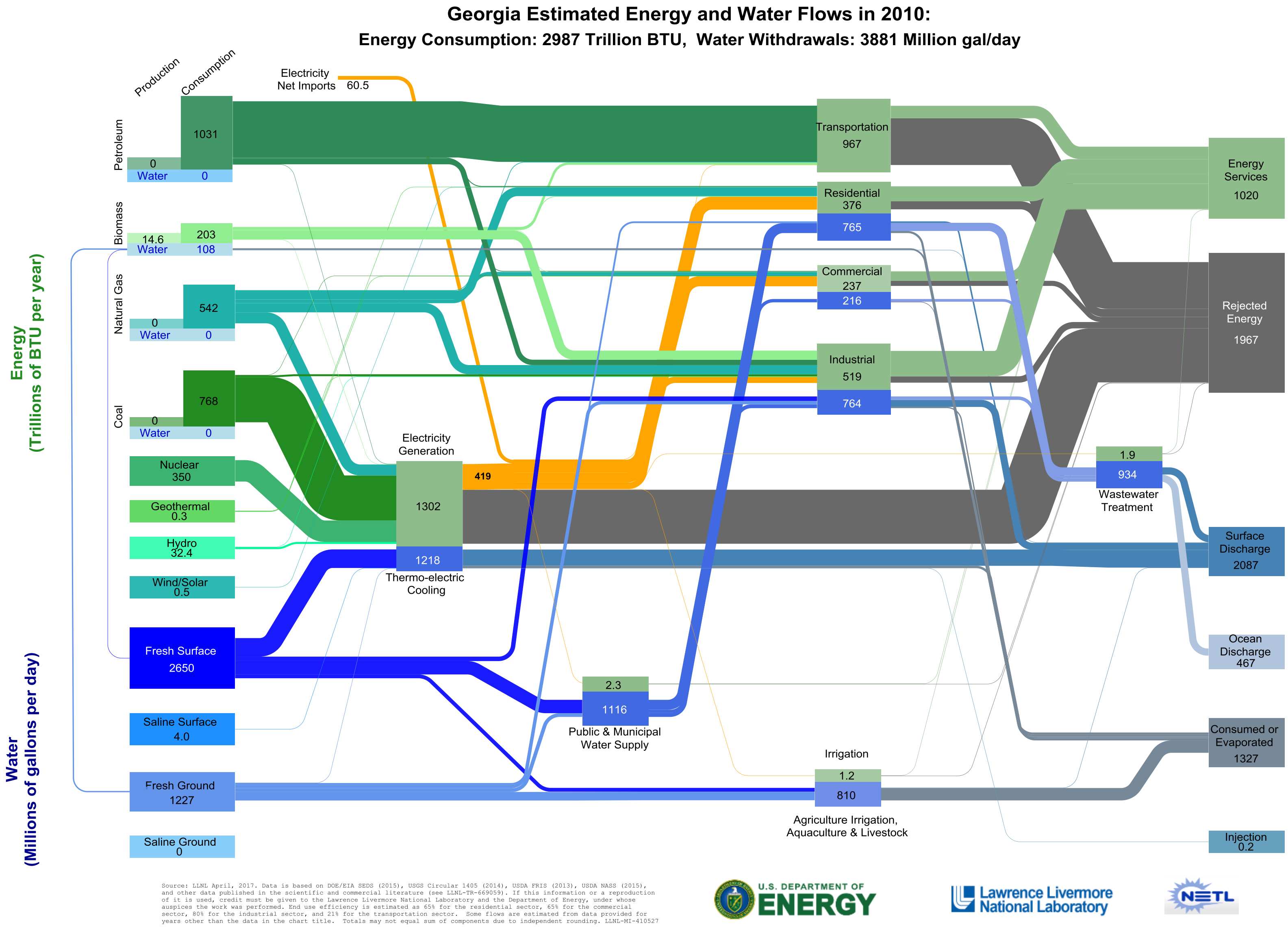


Figure 3-11 - Hybrid Energy-Water Sankey Diagram for Hawaii

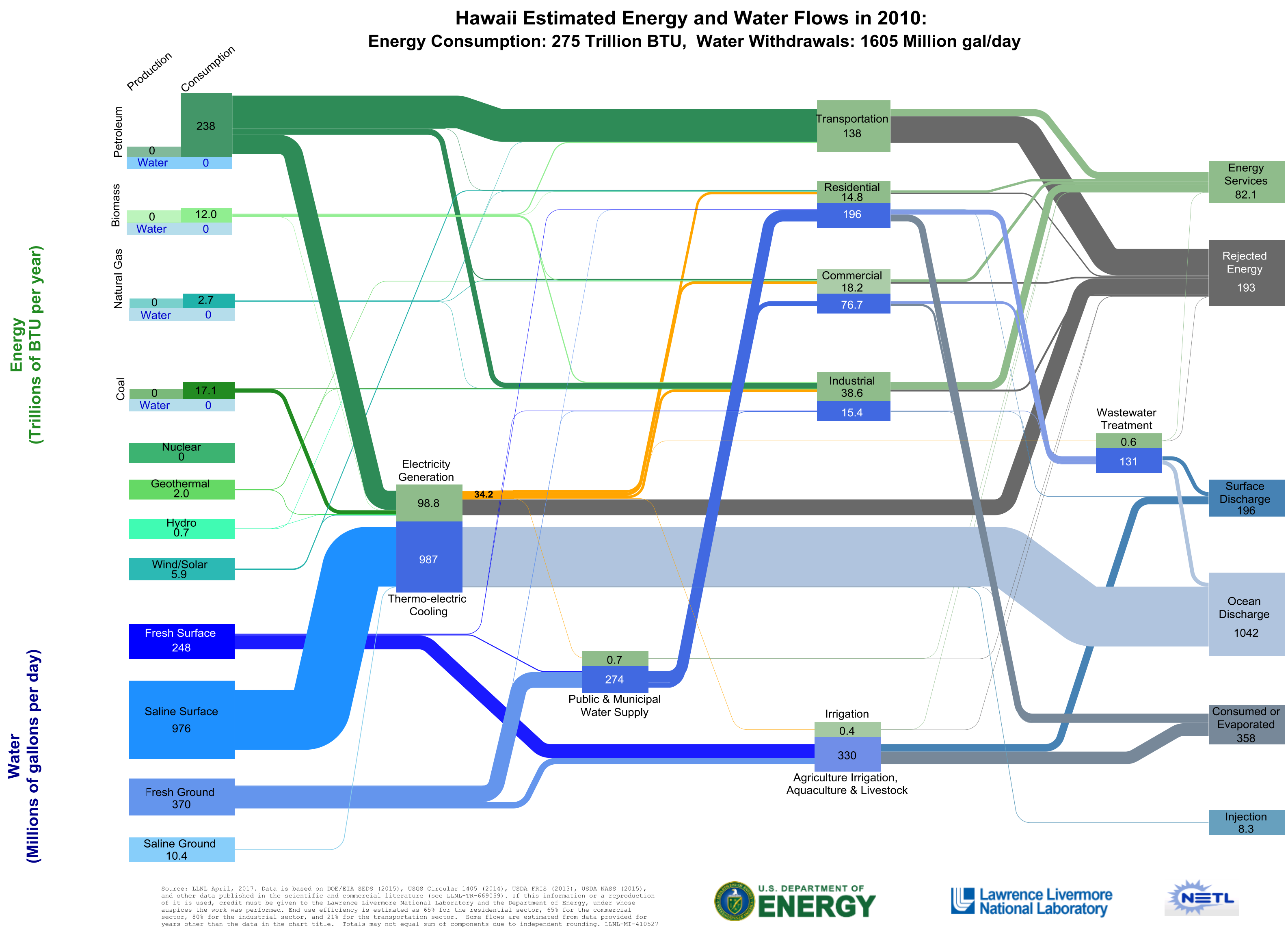


Figure 3-12 - Hybrid Energy-Water Sankey Diagram for Idaho

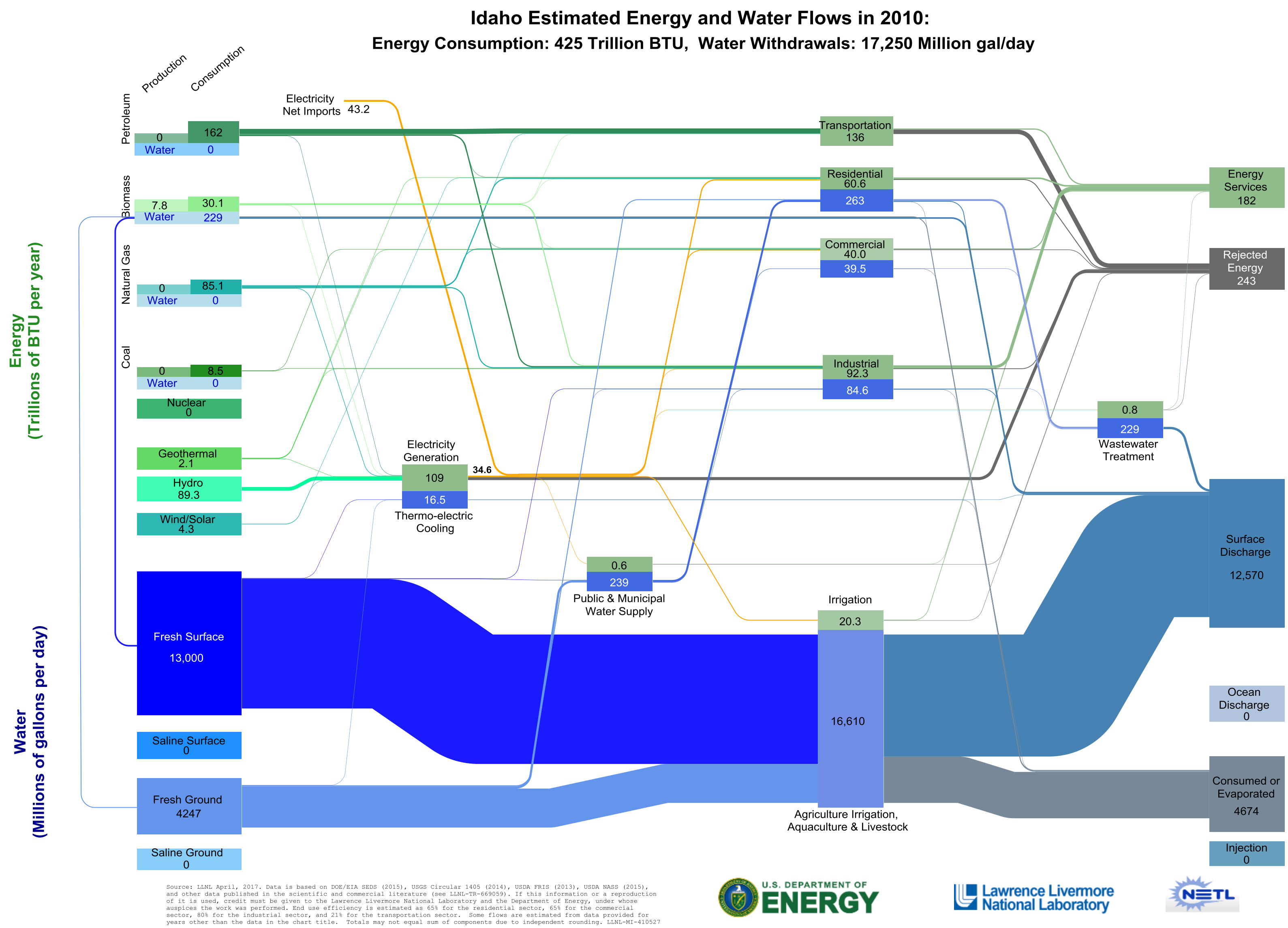


Figure 3-13 - Hybrid Energy-Water Sankey Diagram for Illinois

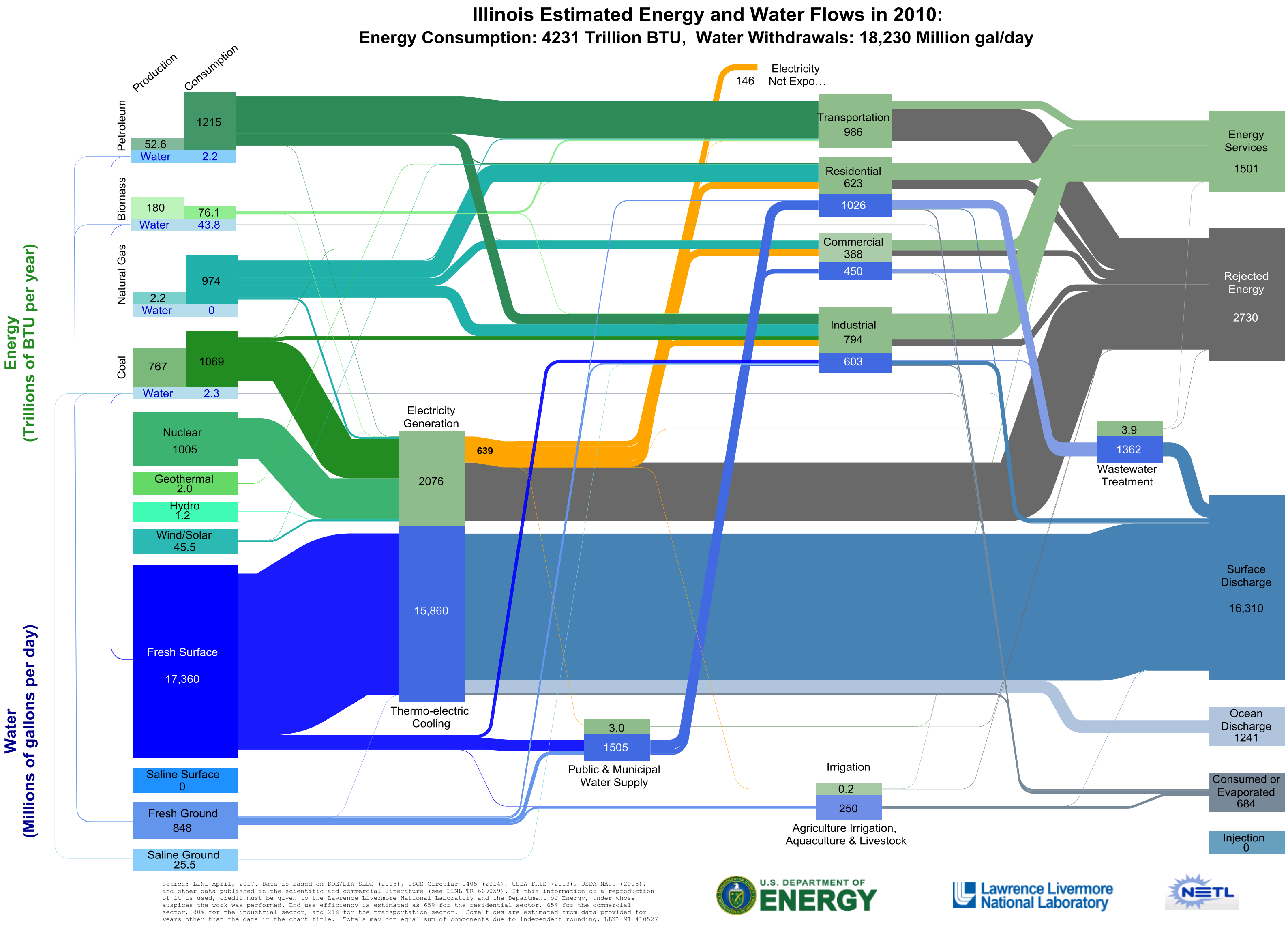


Figure 3-14 - Hybrid Energy-Water Sankey Diagram for Indiana

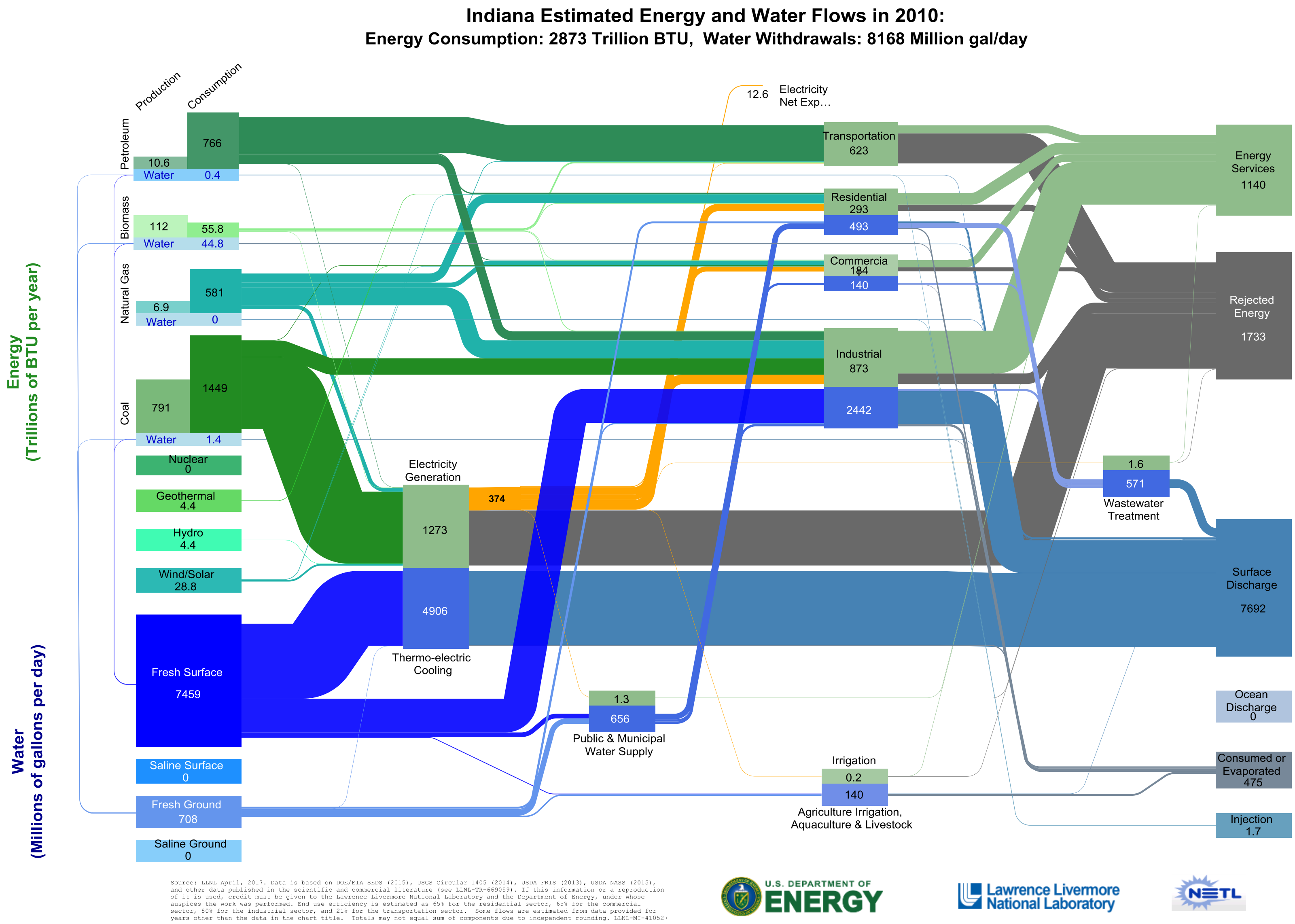


Figure 3-15 - Hybrid Energy-Water Sankey Diagram for Iowa

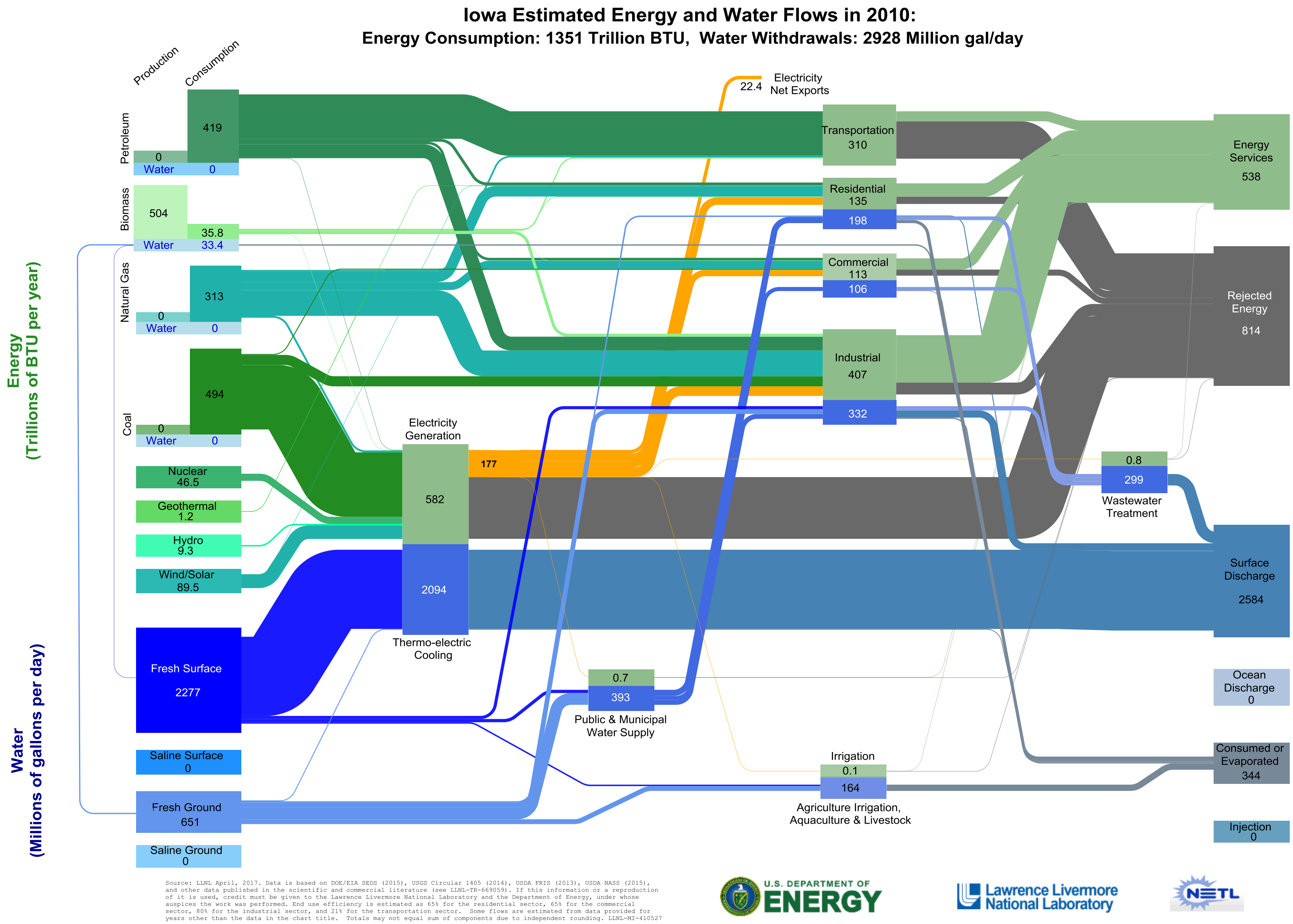


Figure 3-16 - Hybrid Energy-Water Sankey Diagram for Kansas

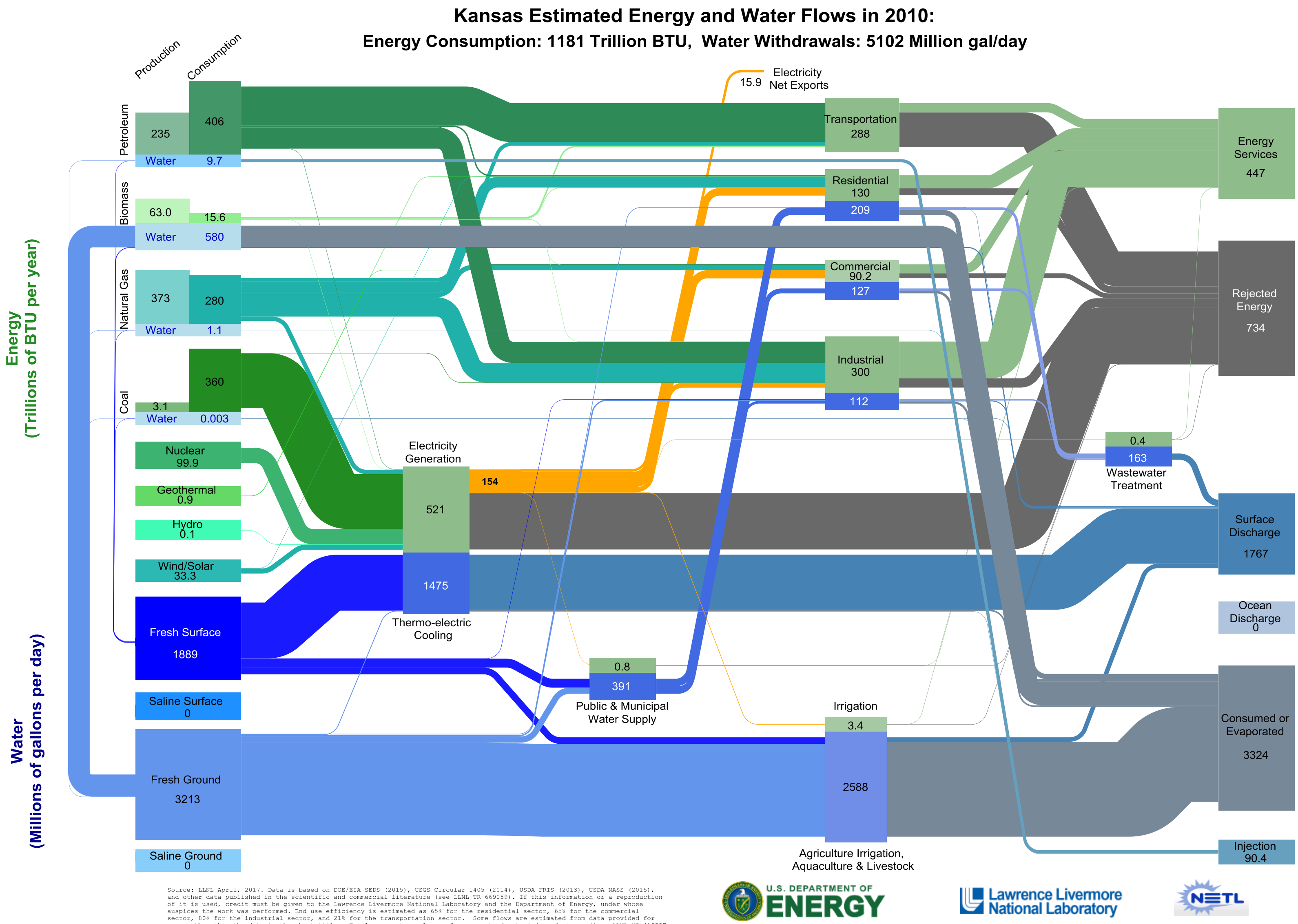


Figure 3-17 - Hybrid Energy-Water Sankey Diagram for Kentucky

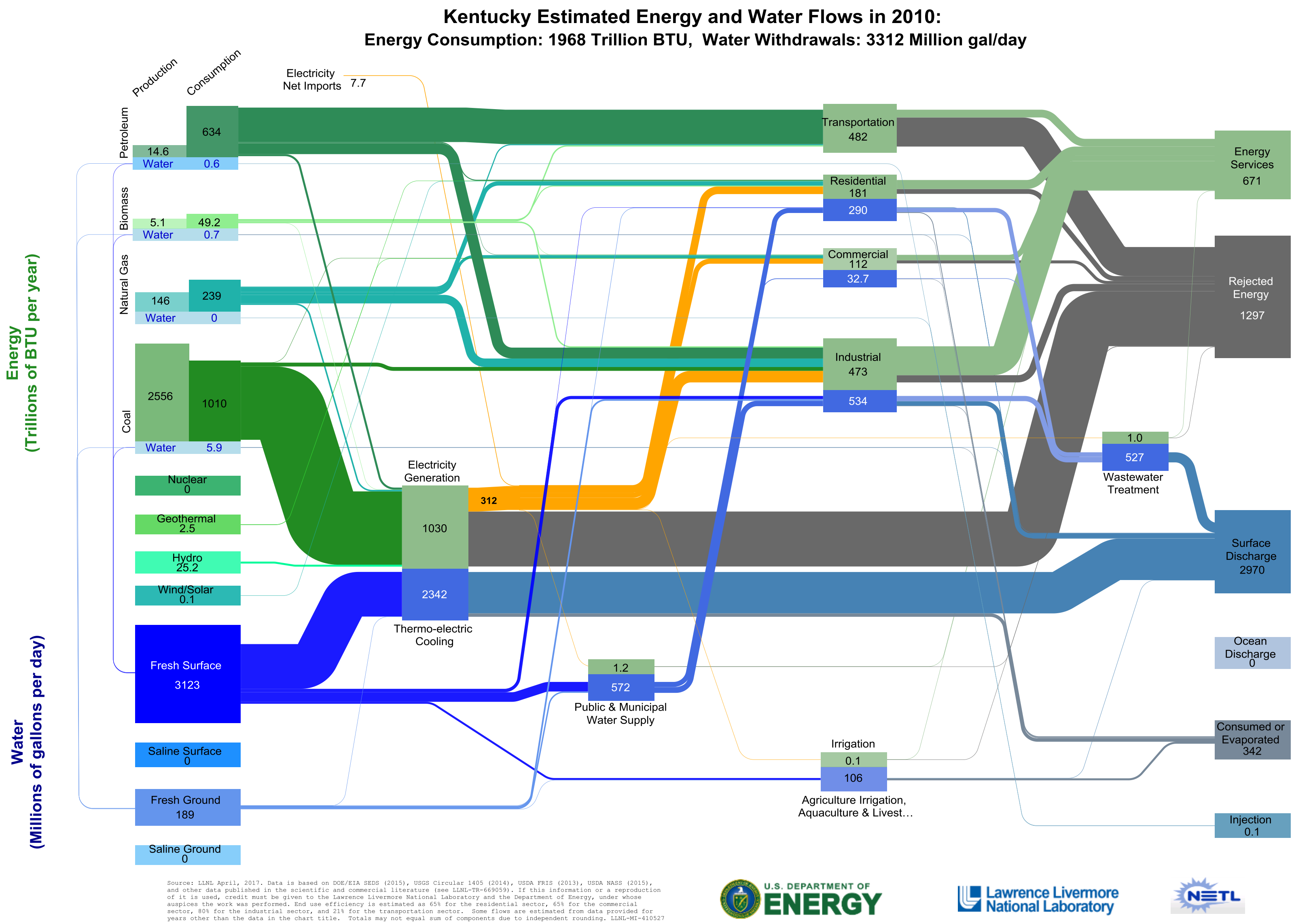


Figure 3-18 - Hybrid Energy-Water Sankey Diagram for Louisiana

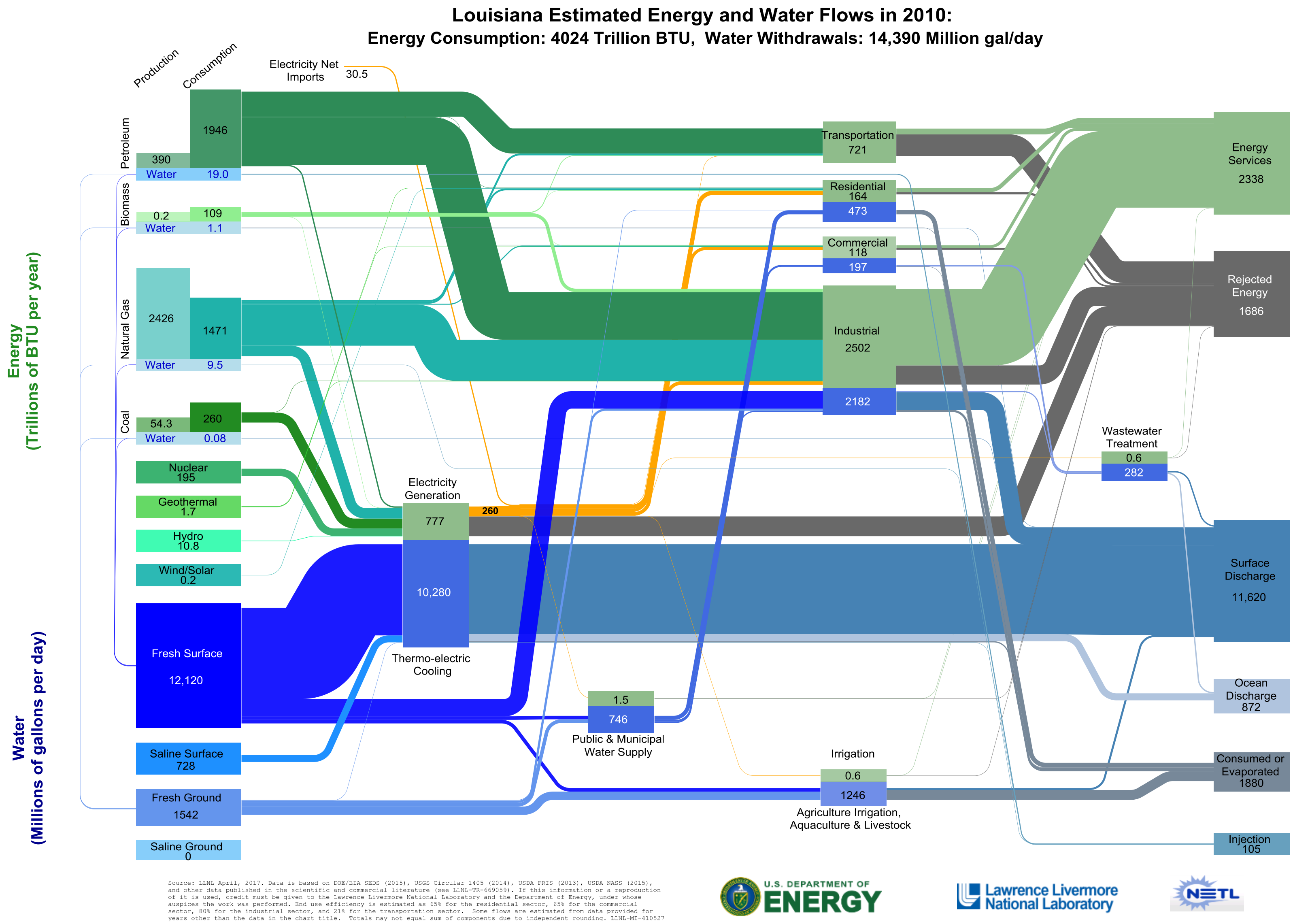


Figure 3-19 - Hybrid Energy-Water Sankey Diagram for Maine

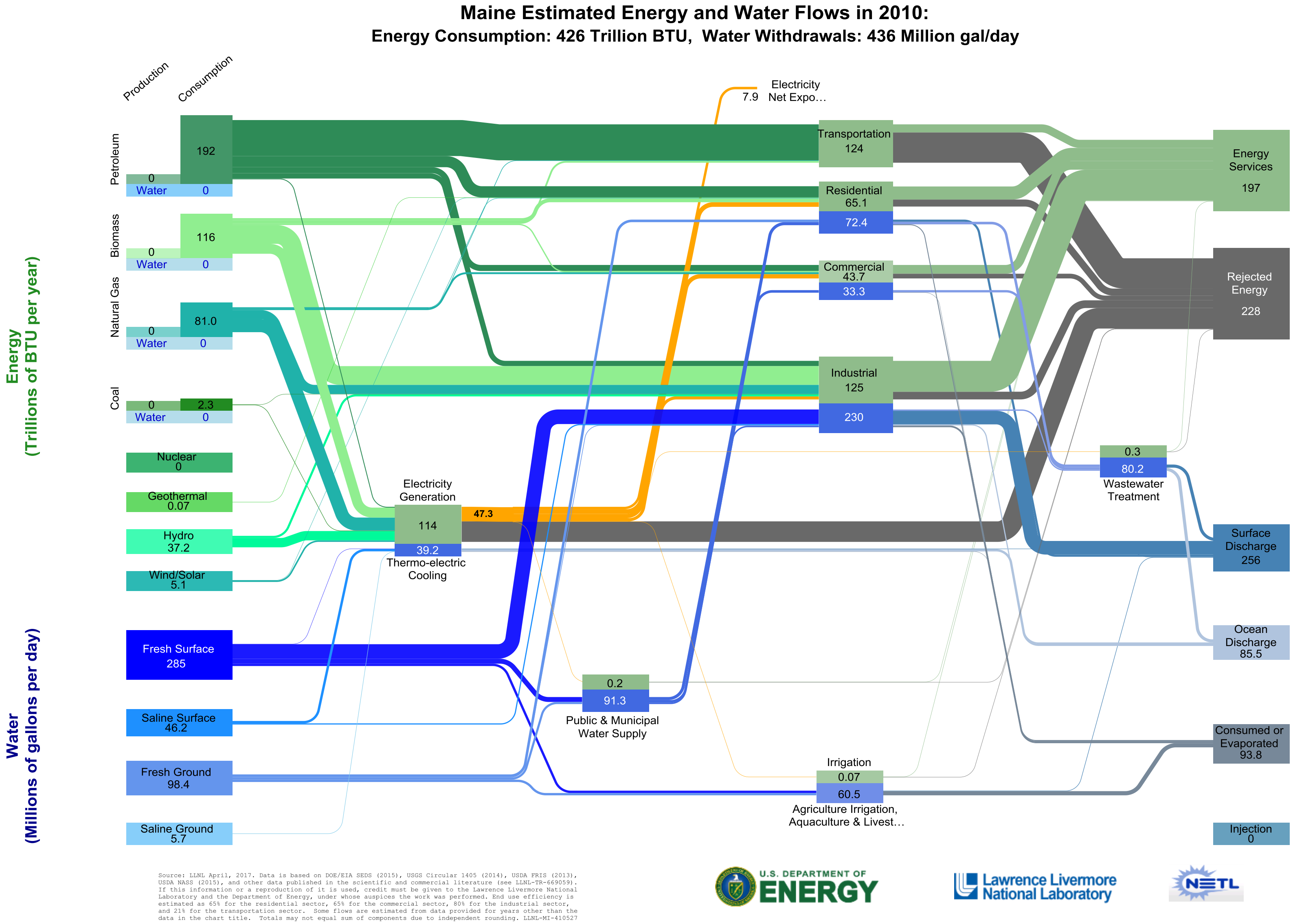


Figure 3-20 - Hybrid Energy-Water Sankey Diagram for Maryland

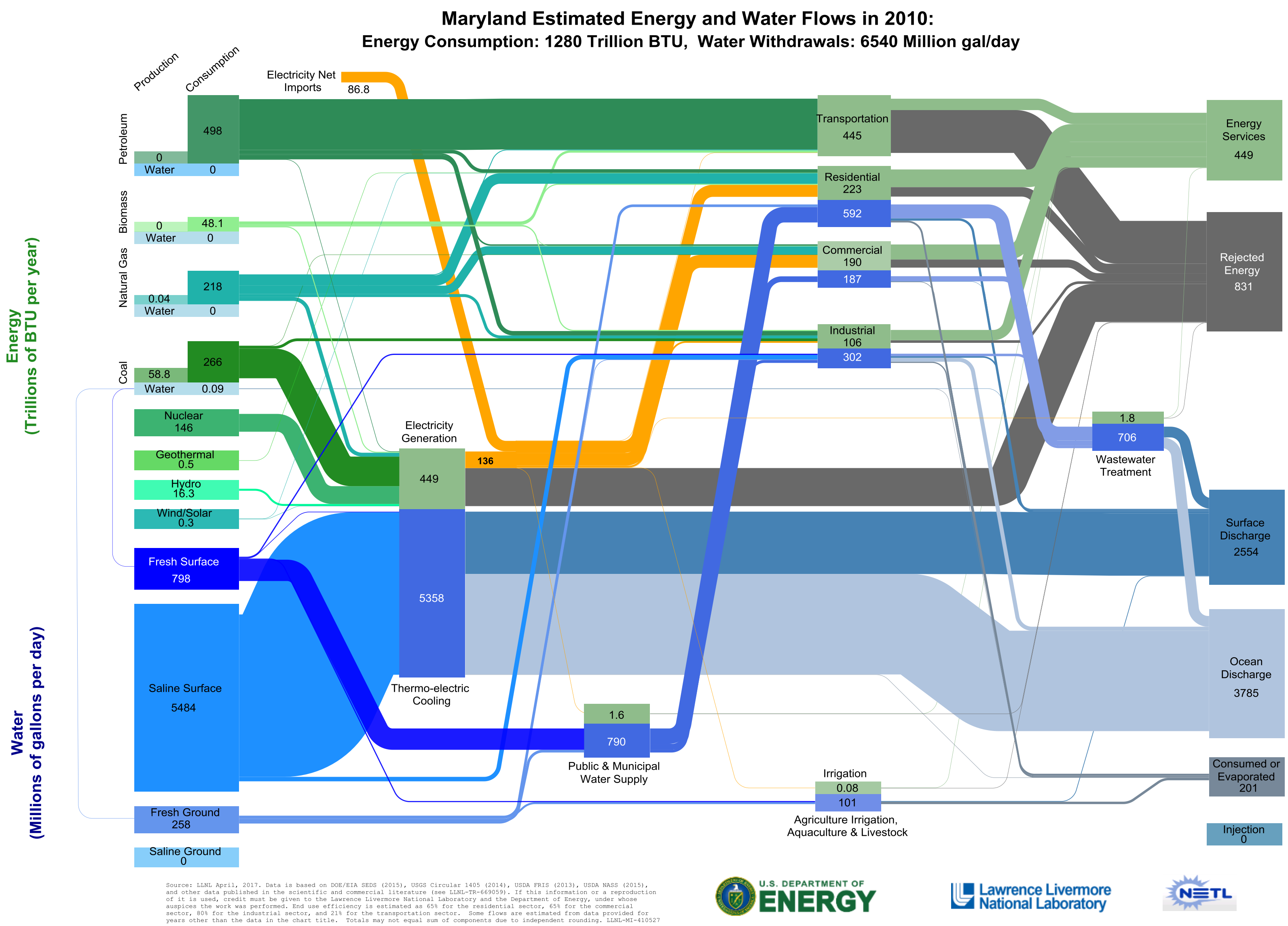


Figure 3-21 - Hybrid Energy-Water Sankey Diagram for Massachusetts

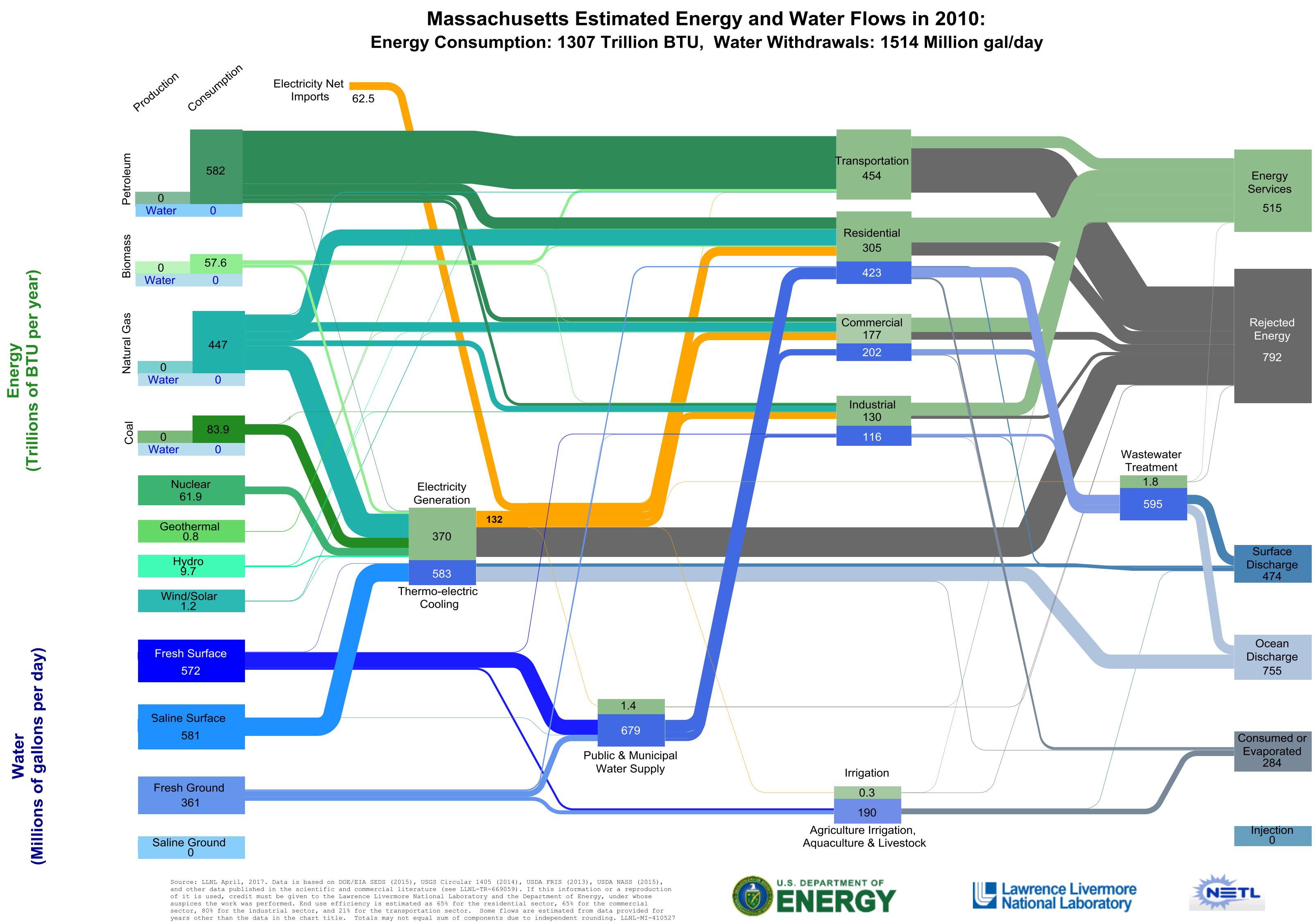


Figure 3-22 - Hybrid Energy-Water Sankey Diagram for Michigan

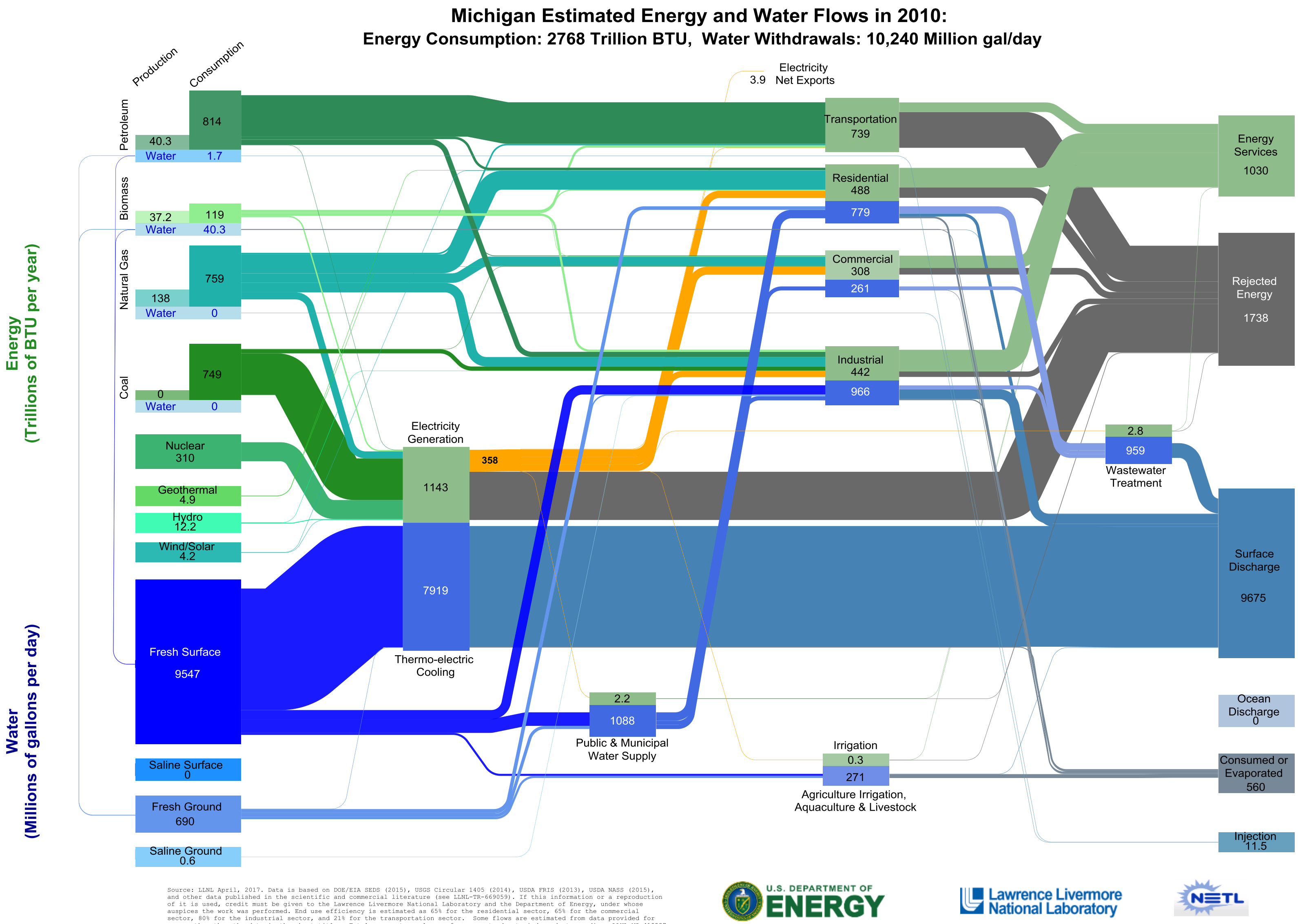
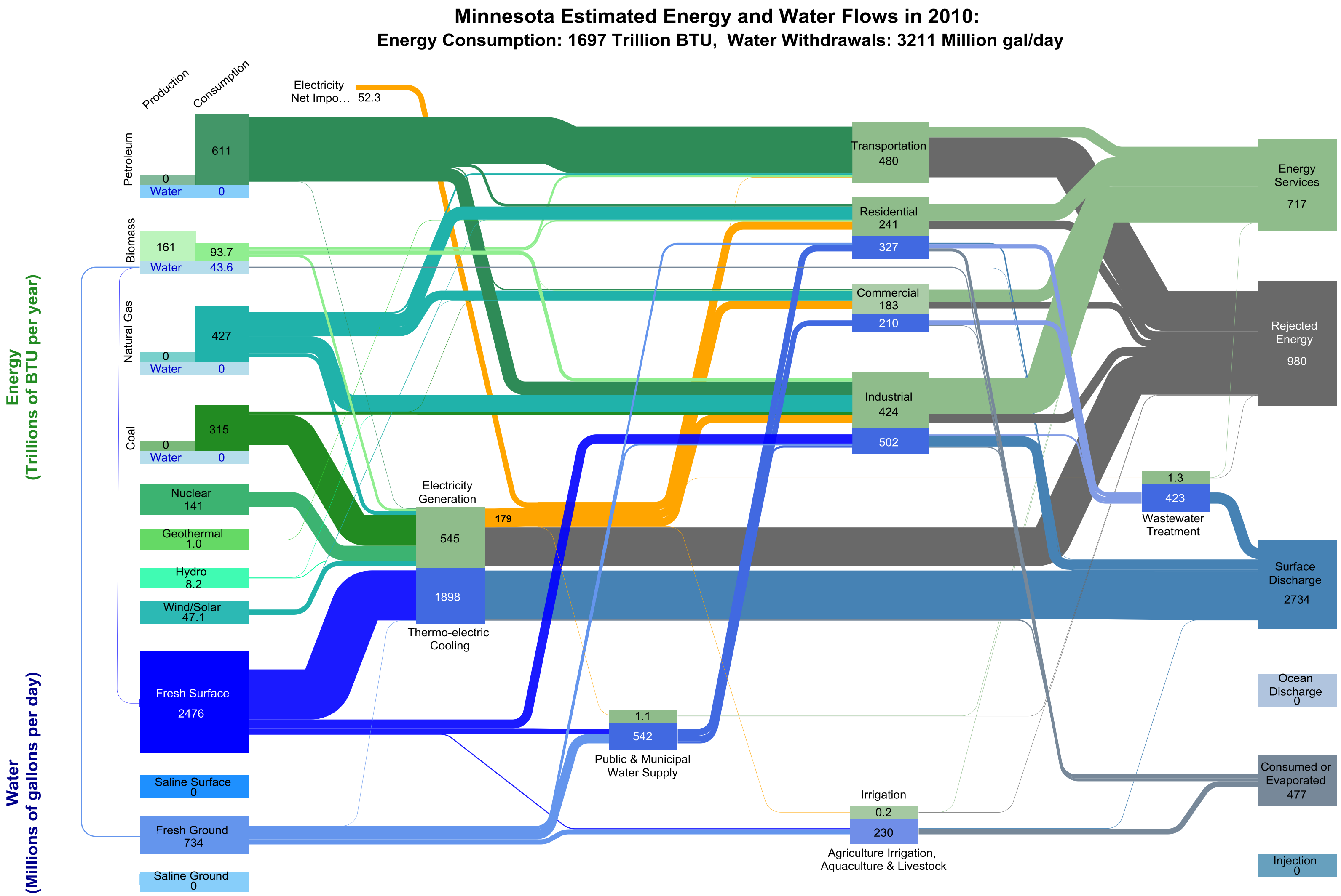
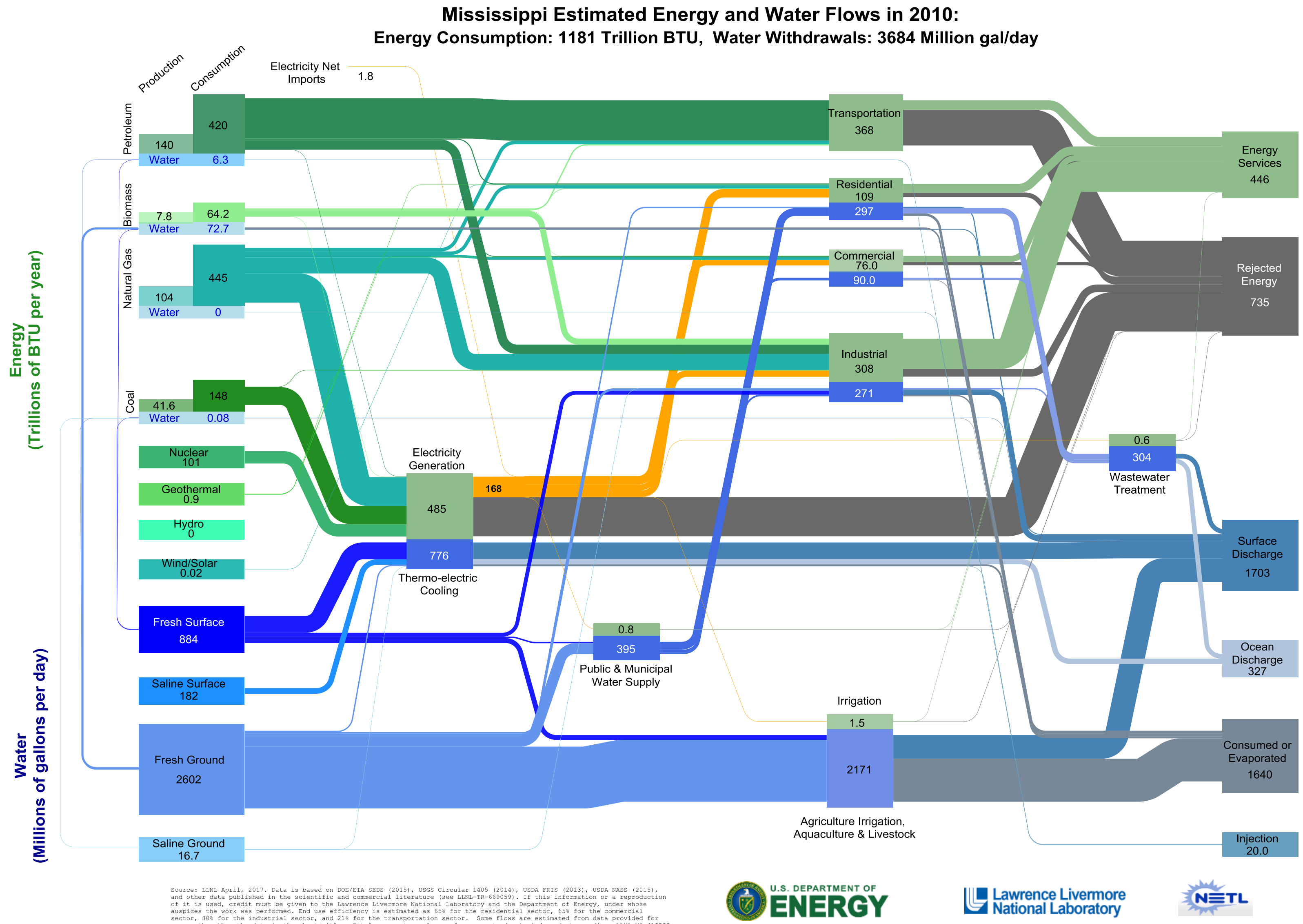


Figure 3-23 - Hybrid Energy-Water Sankey Diagram for Minnesota



Source: LLNL April, 2017. Data is based on DOE/EIA SEDS (2015), USGS Circular 1405 (2014), USDA FRIS (2013), USDA NASS (2015), and other data published in the scientific and commercial literature (see LLNL-TR-669059). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Some flows are estimated from data provided for years other than the data in the chart title. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 3-24 - Hybrid Energy-Water Sankey Diagram for Mississippi



Source: LLNL April, 2017. Data is based on DOE/EIA SEDS (2015), USGS Circular 1405 (2014), USDA FRIS (2013), USDA NASS (2015), and other data published in the scientific and commercial literature (see LLNL-TR-669059). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Some flows are estimated from data provided for years other than the data in the chart title. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 3-25 - Hybrid Energy-Water Sankey Diagram for Missouri

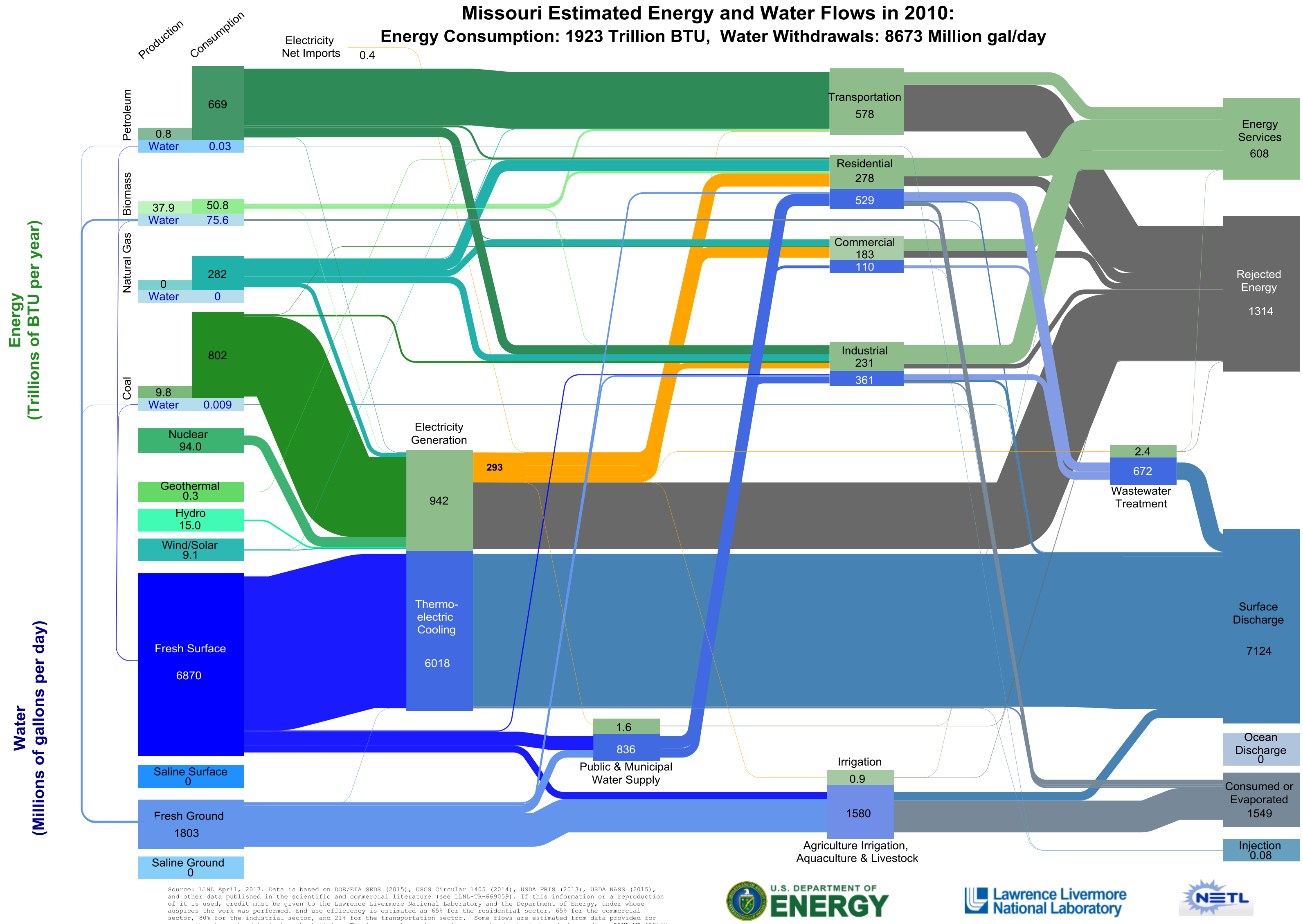


Figure 3-26 - Hybrid Energy-Water Sankey Diagram for Montana

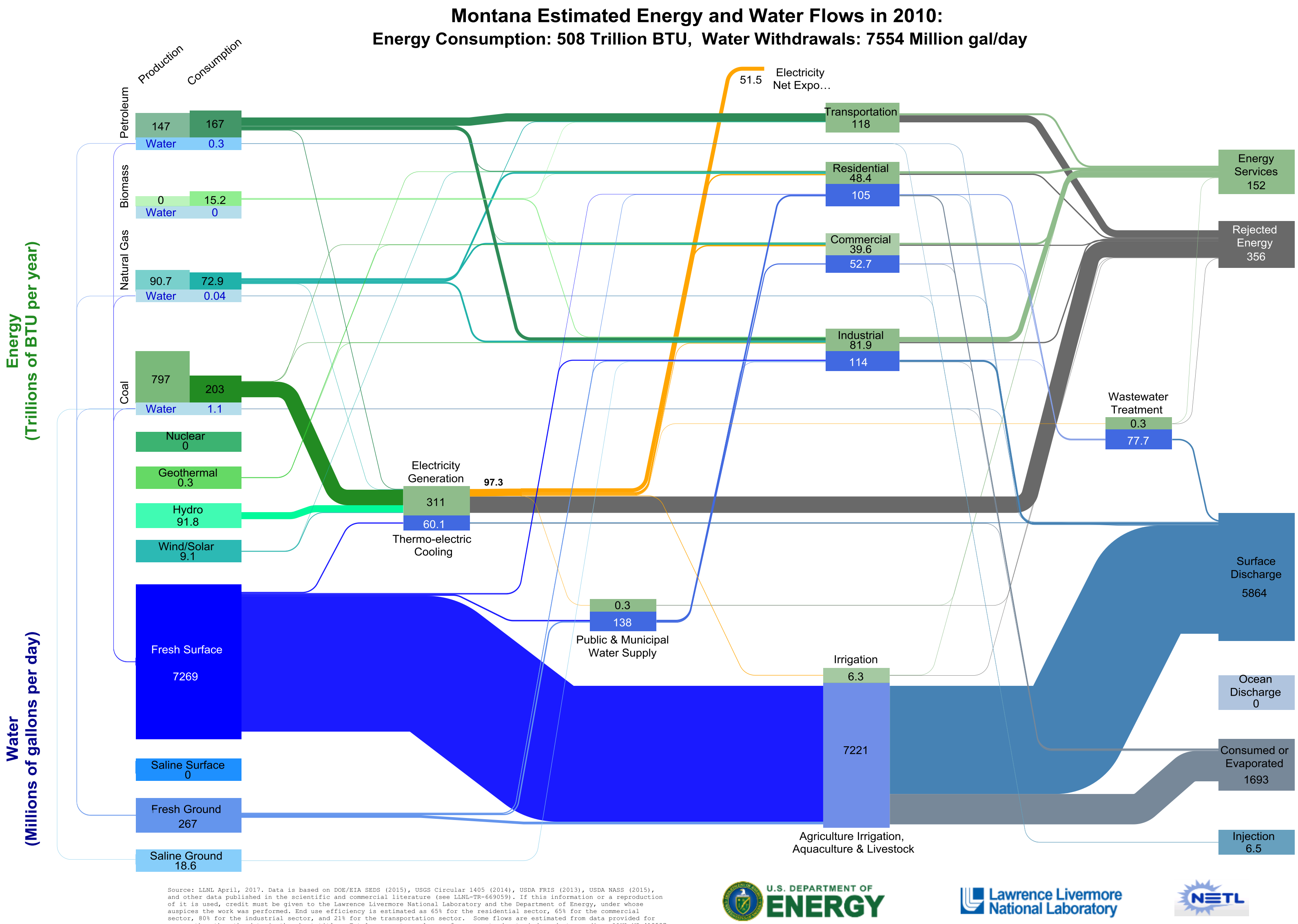


Figure 3-27 - Hybrid Energy-Water Sankey Diagram for Nebraska

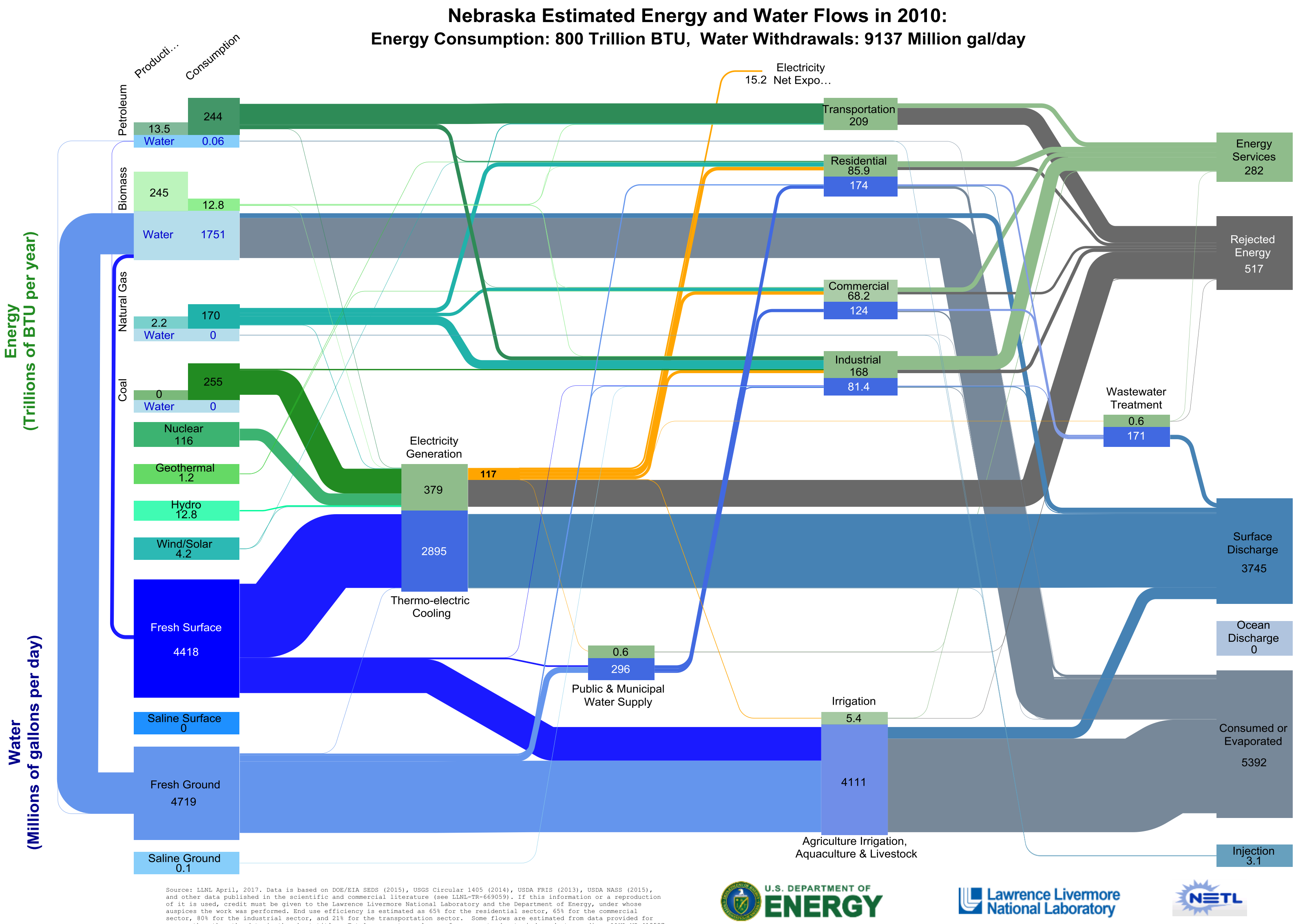


Figure 3-28 - Hybrid Energy-Water Sankey Diagram for Nevada

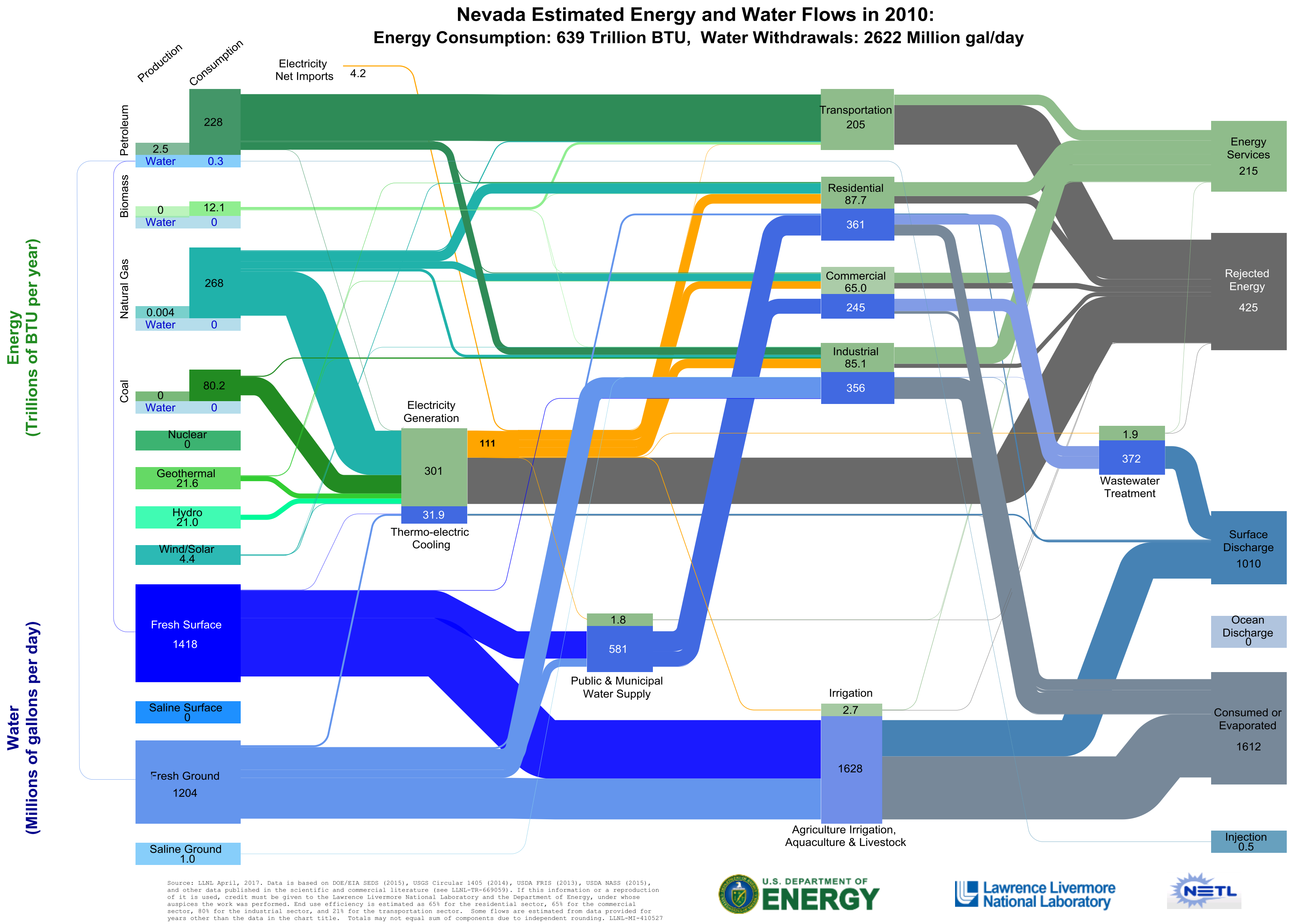


Figure 3-29 - Hybrid Energy-Water Sankey Diagram for New Hampshire

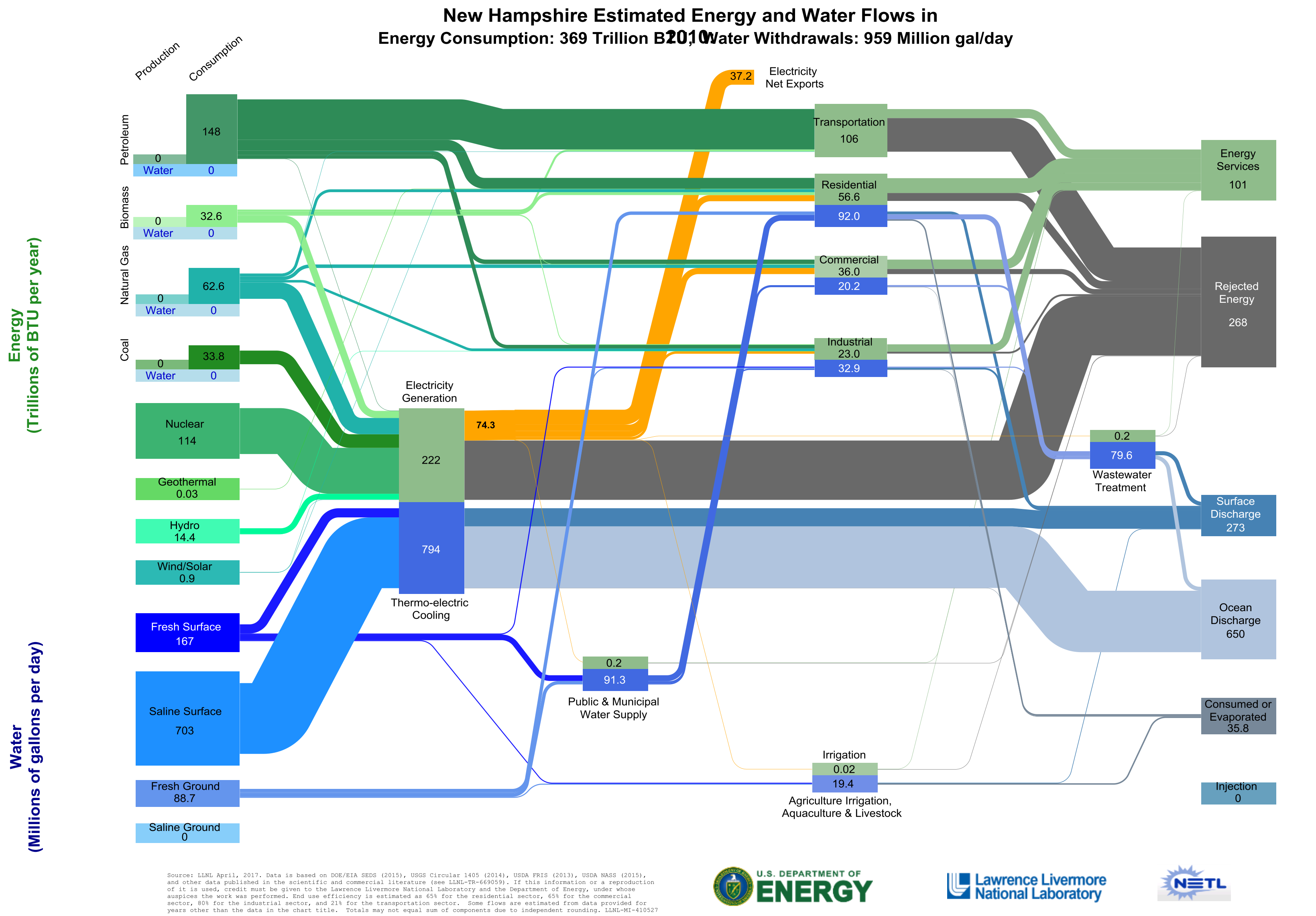


Figure 3-30 - Hybrid Energy-Water Sankey Diagram for New Jersey

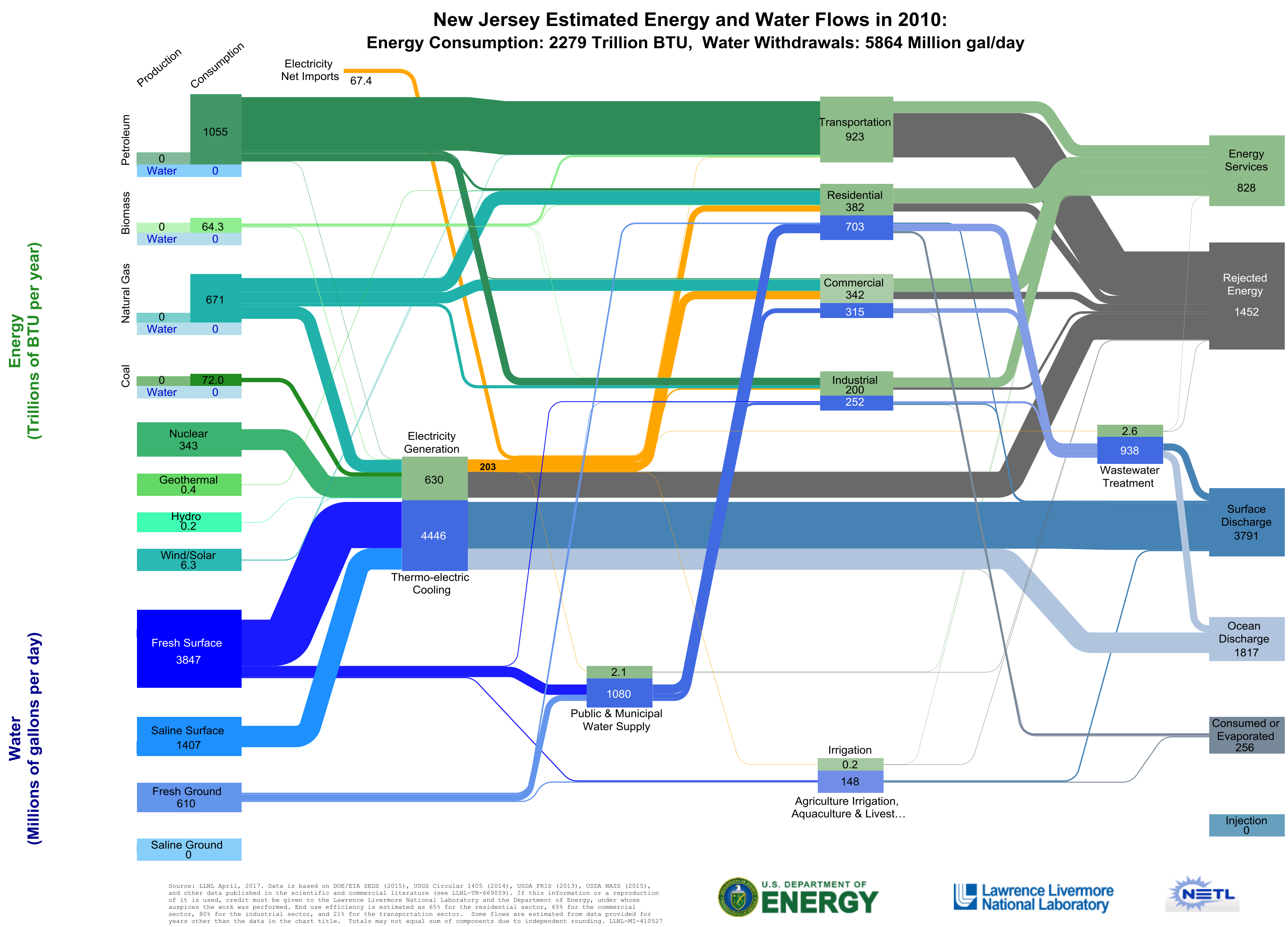


Figure 3-31 - Hybrid Energy-Water Sankey Diagram for New Mexico

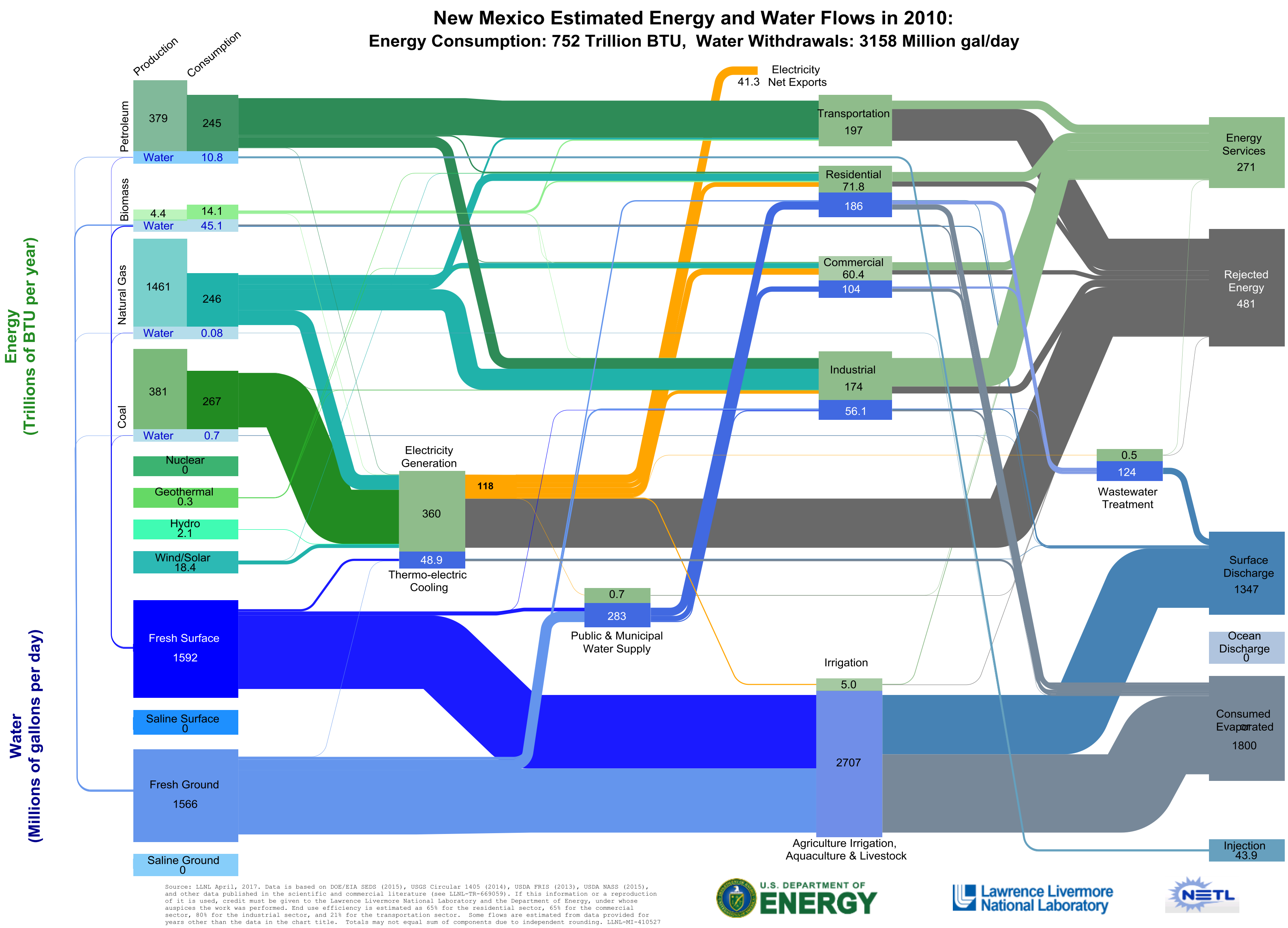


Figure 3-32 - Hybrid Energy-Water Sankey Diagram for New York

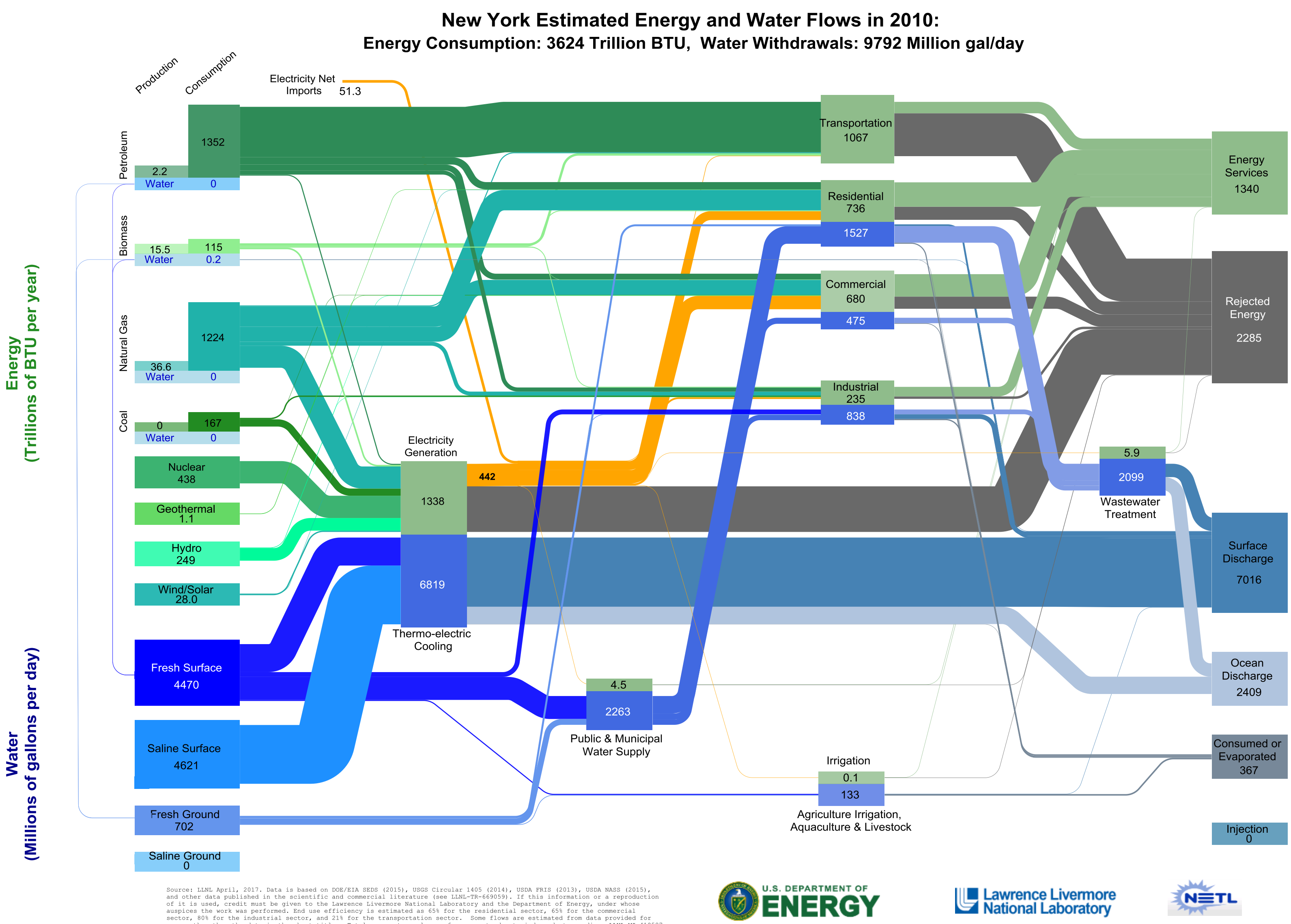


Figure 3-33- Hybrid Energy-Water Sankey Diagram for North Carolina

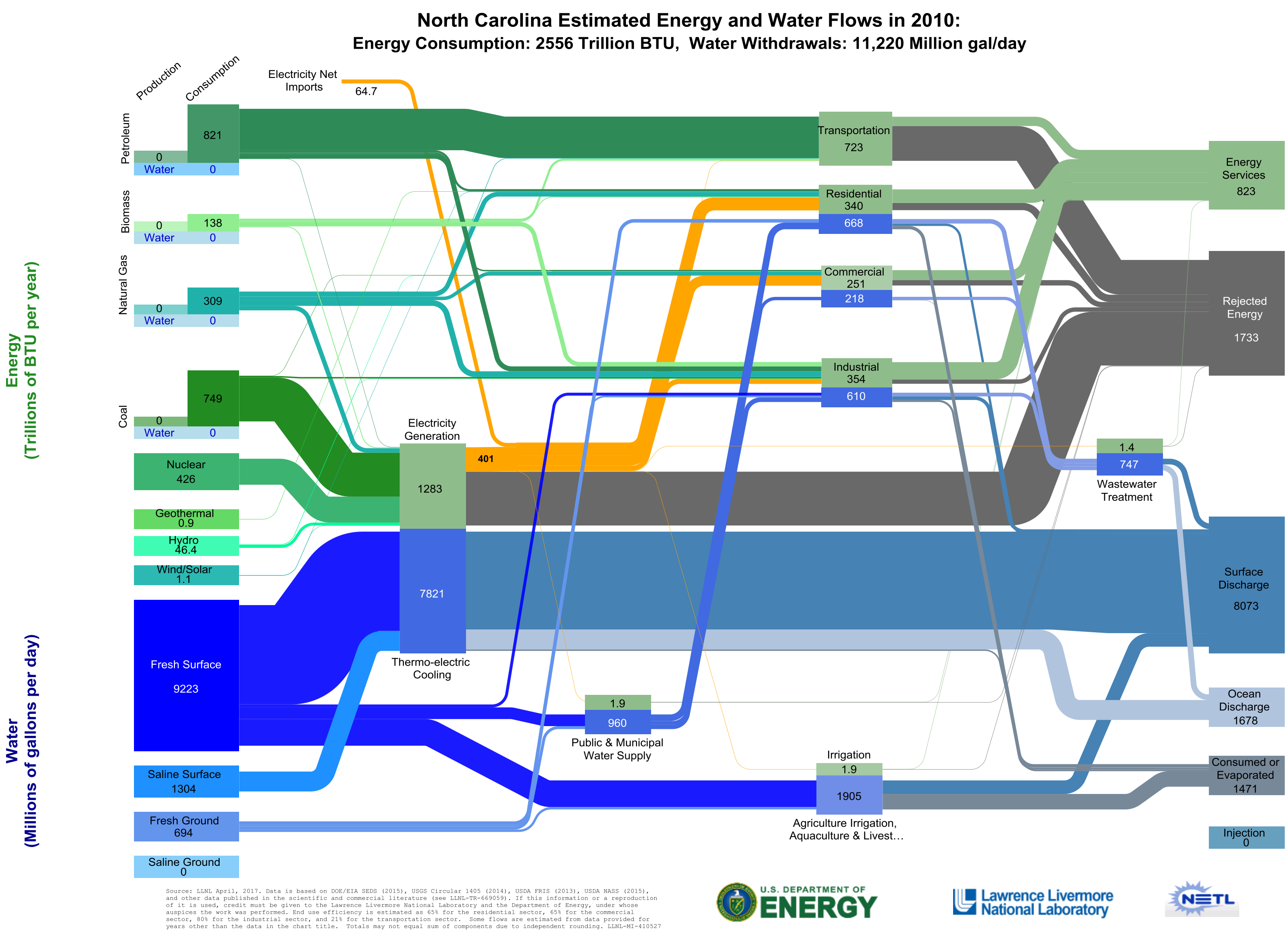


Figure 3-34 - Hybrid Energy-Water Sankey Diagram for North Dakota

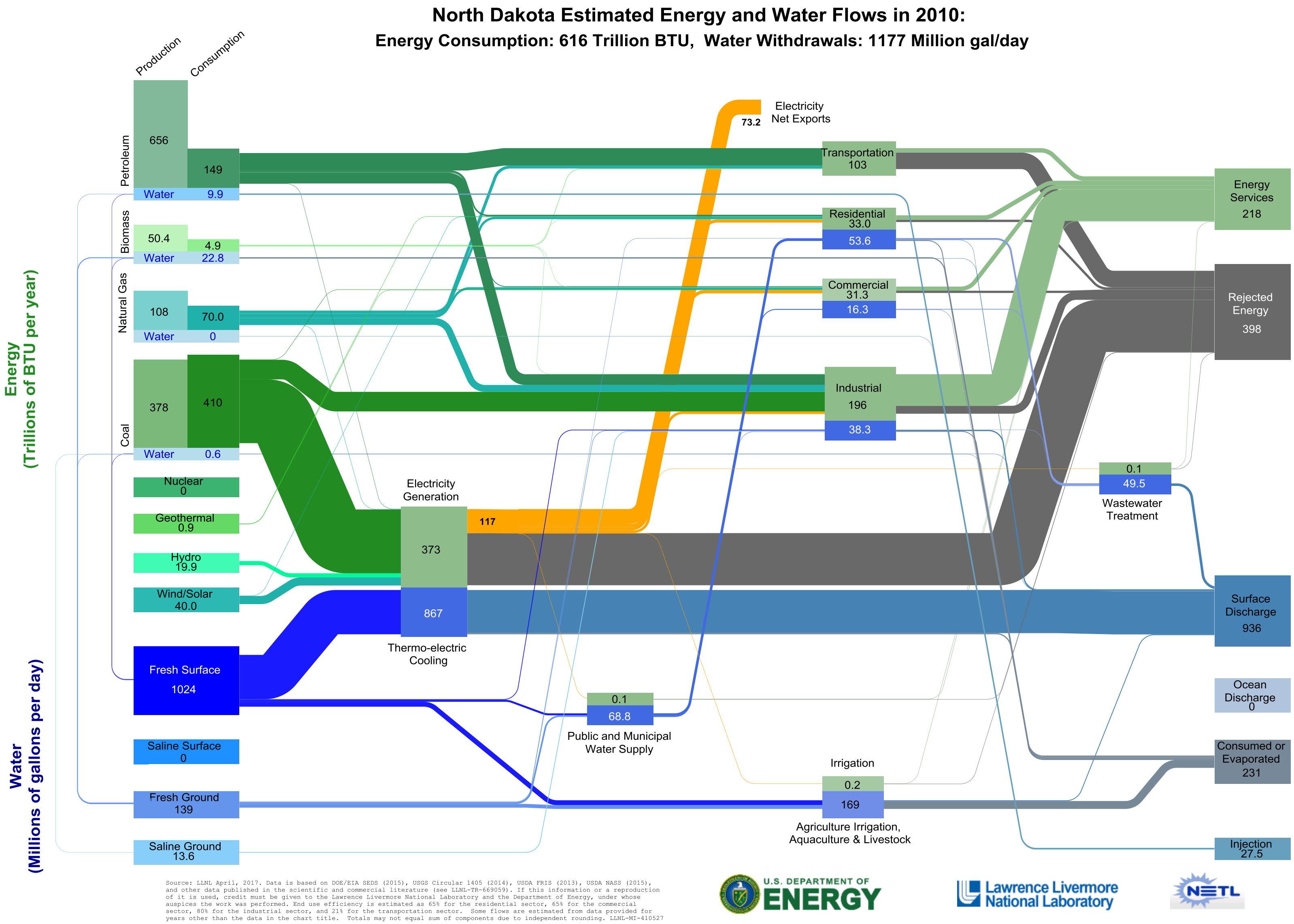
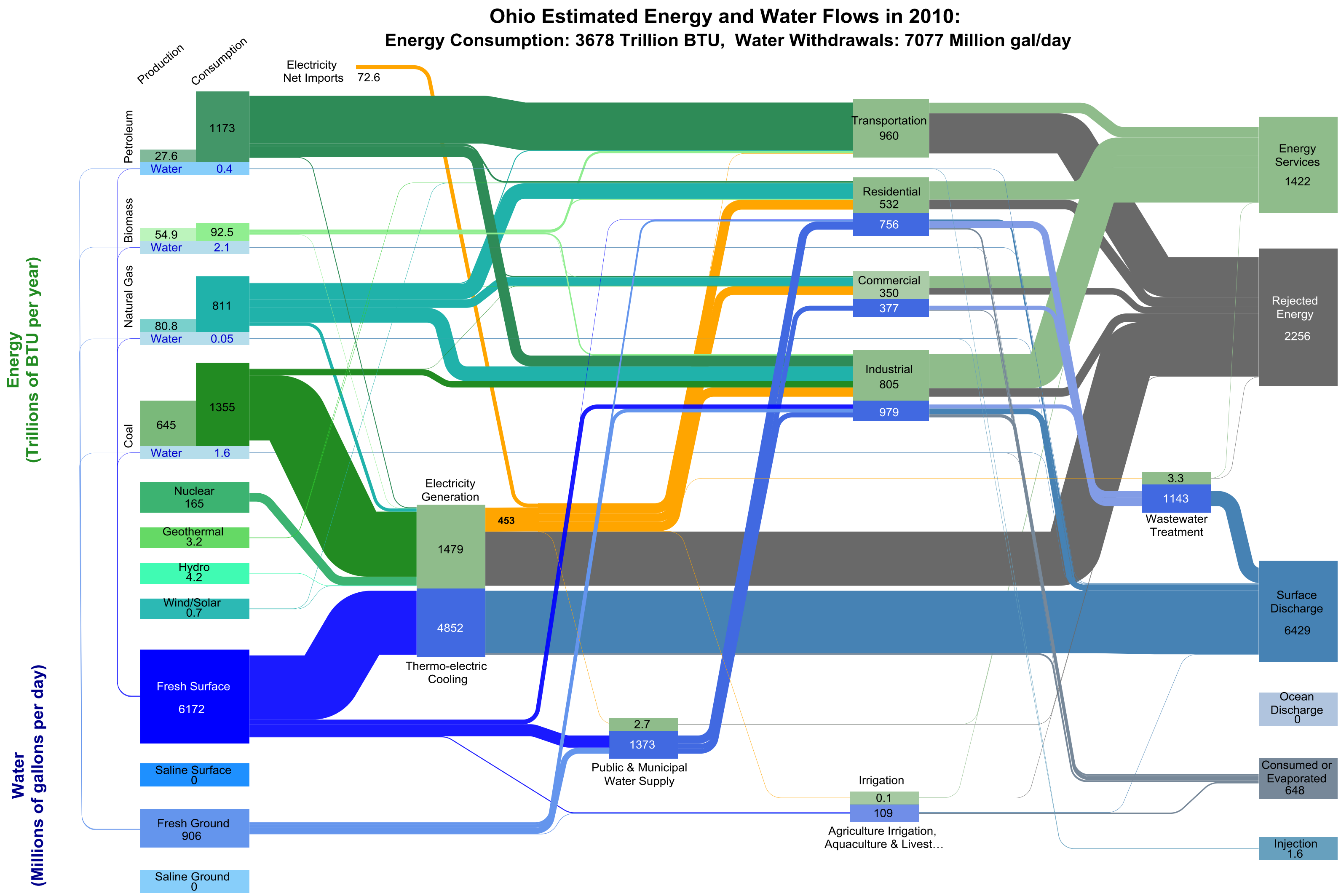


Figure 3-35 - Hybrid Energy-Water Sankey Diagram for Ohio



Source: LLNL April, 2017. Data is based on DOE/EIA SEDS (2015), USGS Circular 1405 (2014), USDA FRIS (2013), USDA NASS (2015), and other data published in the scientific and commercial literature (see LLNL-TR-669059). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Some flows are estimated from data provided for years other than the data in the chart title. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 3-36 - Hybrid Energy-Water Sankey Diagram for Oklahoma

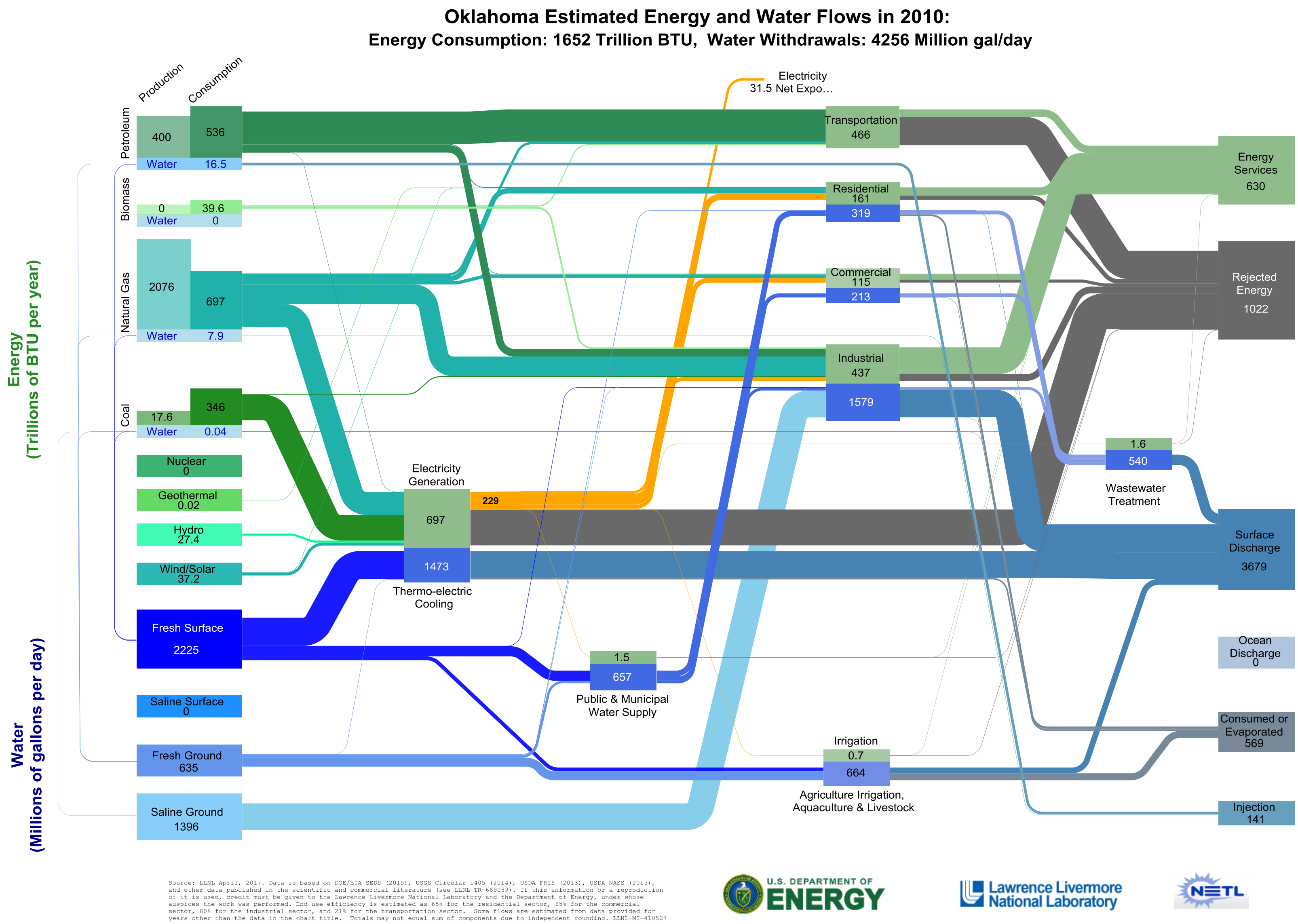


Figure 3-37 - Hybrid Energy-Water Sankey Diagram for Oregon

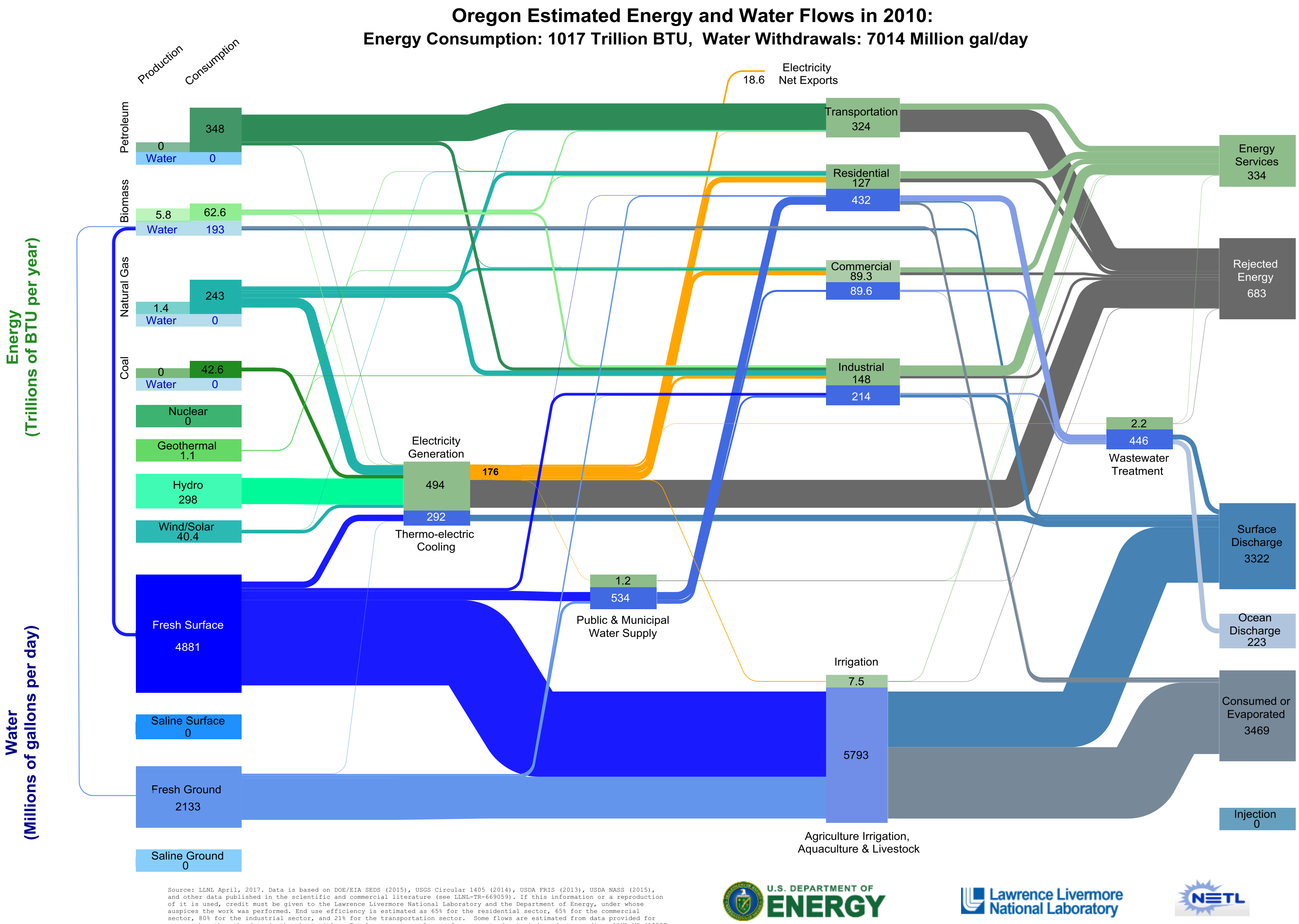


Figure 3-38 - Hybrid Energy-Water Sankey Diagram for Pennsylvania

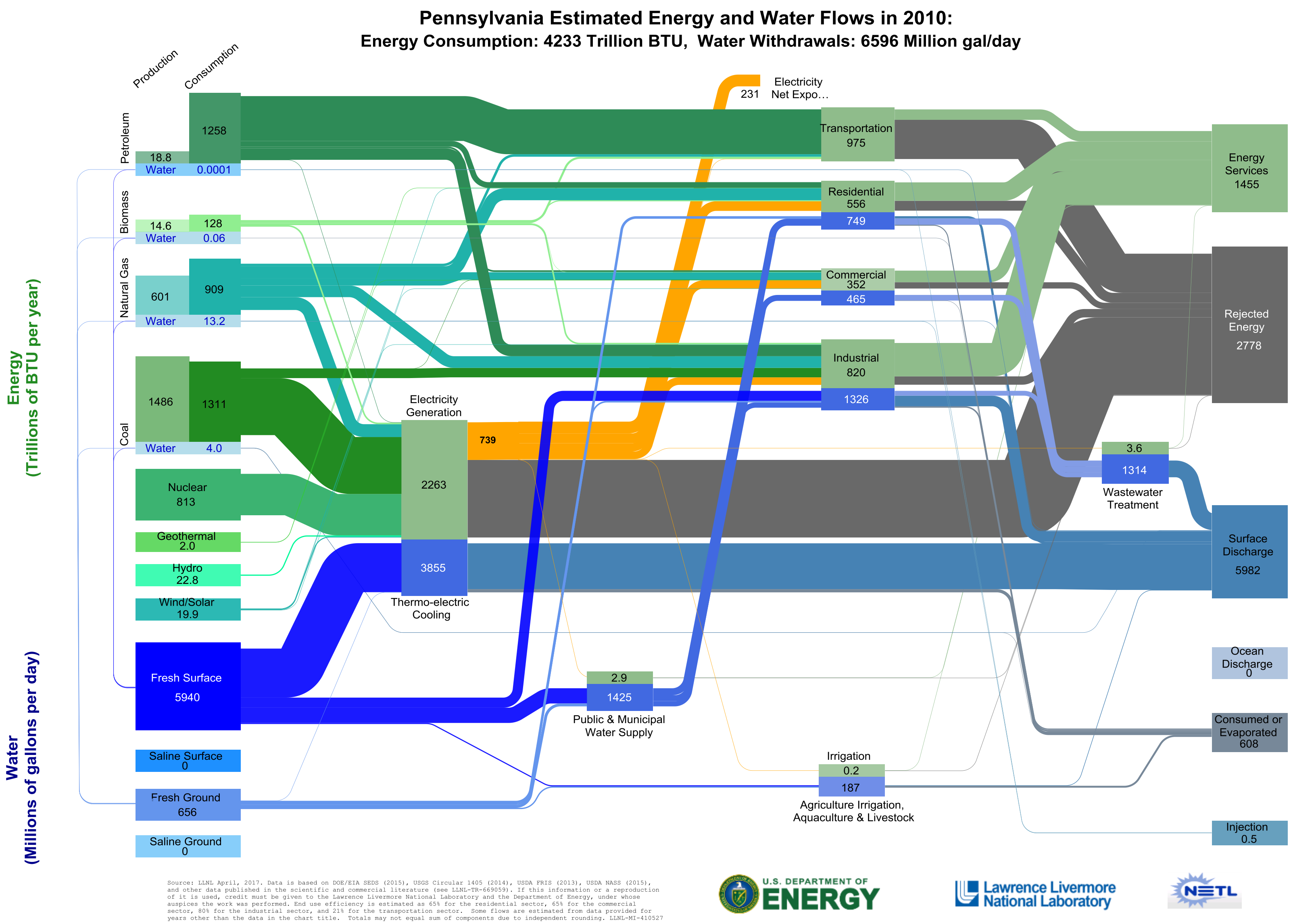


Figure 3-39 - Hybrid Energy-Water Sankey Diagram for Rhode Island

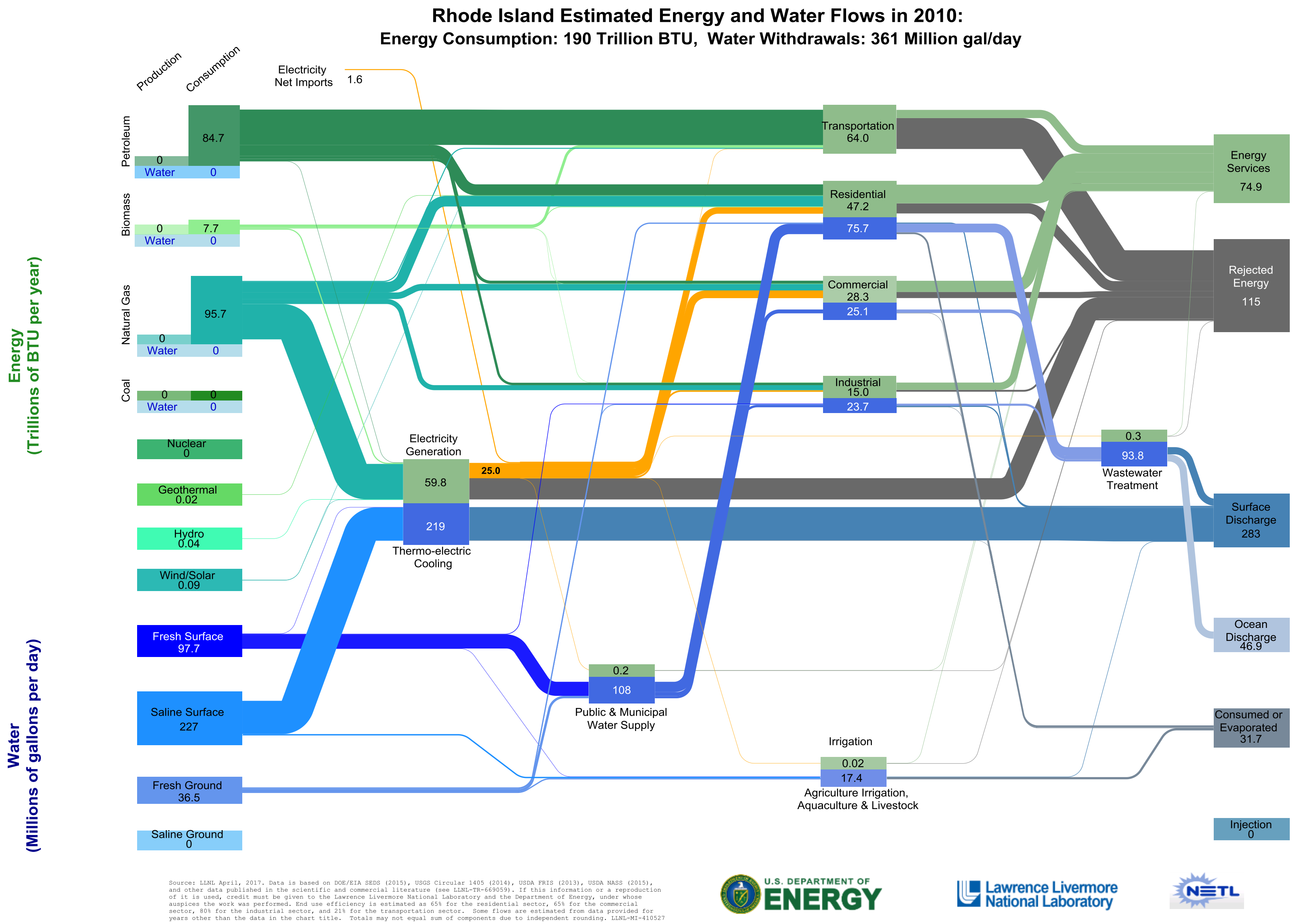


Figure 3-40 - Hybrid Energy-Water Sankey Diagram for South Carolina

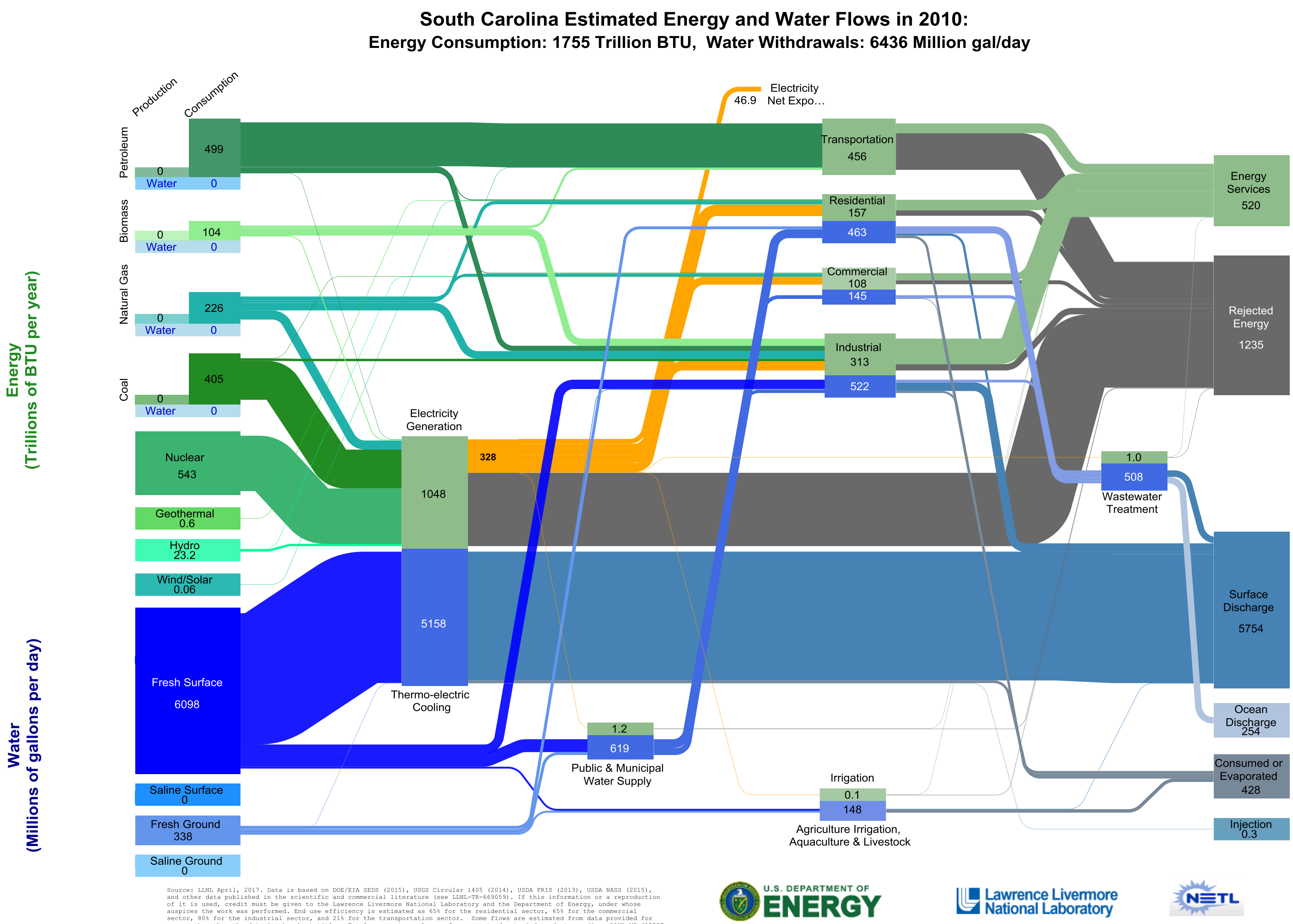


Figure 3-41 - Hybrid Energy-Water Sankey Diagram for South Dakota

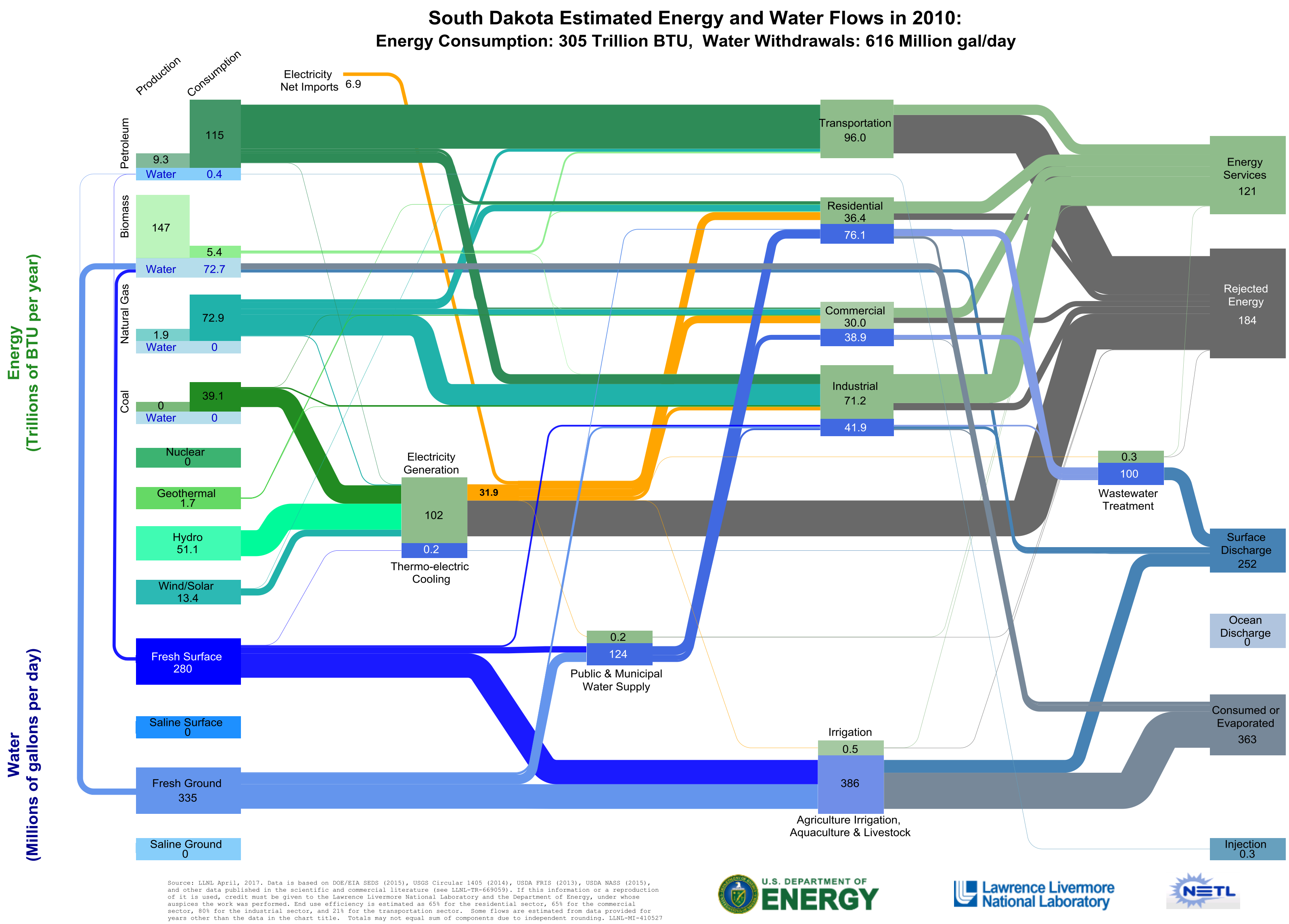


Figure 3-42 - Hybrid Energy-Water Sankey Diagram for Tennessee

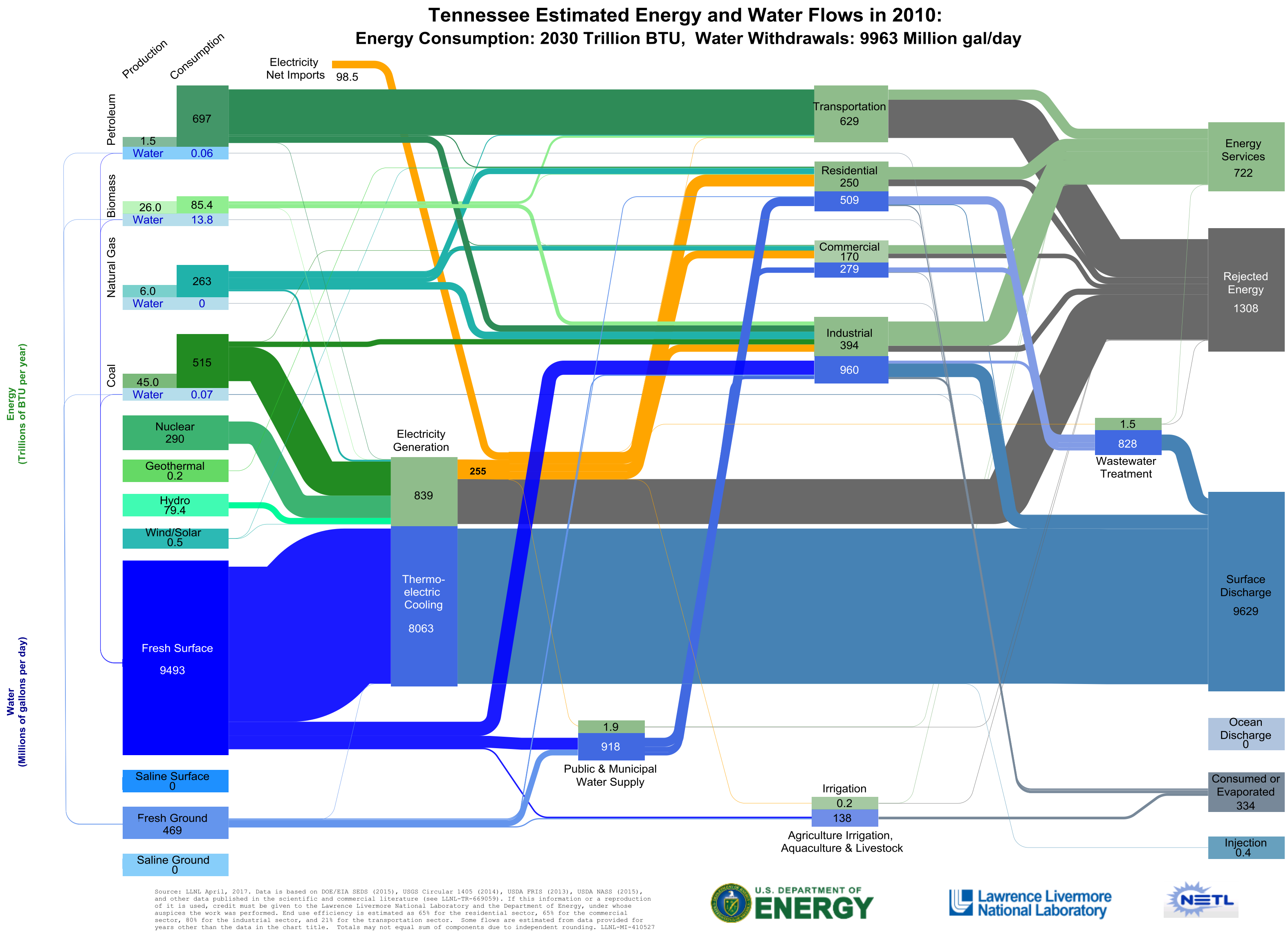


Figure 3-43 - Hybrid Energy-Water Sankey Diagram for Texas

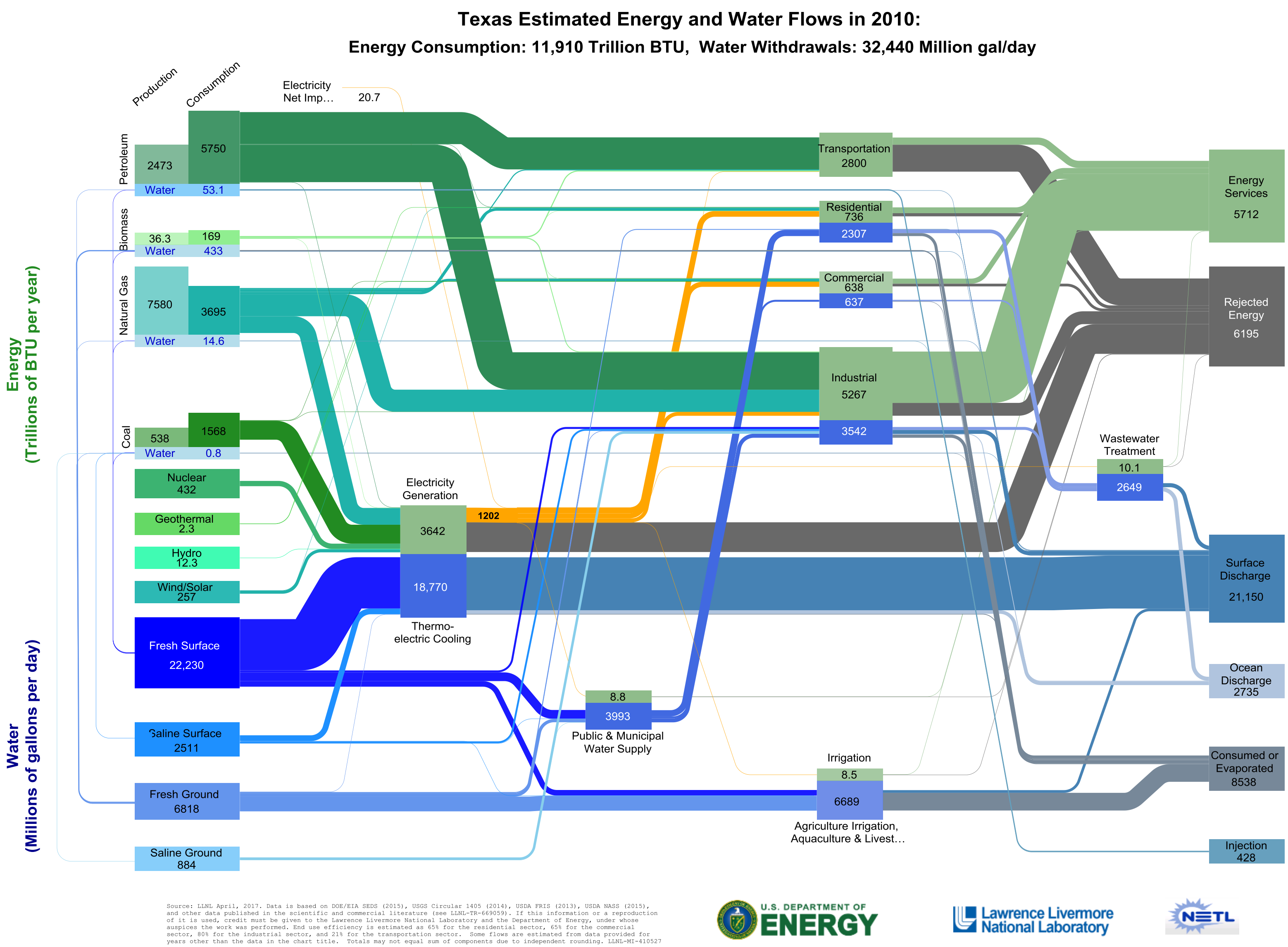


Figure 3-44 - Hybrid Energy-Water Sankey Diagram for Utah

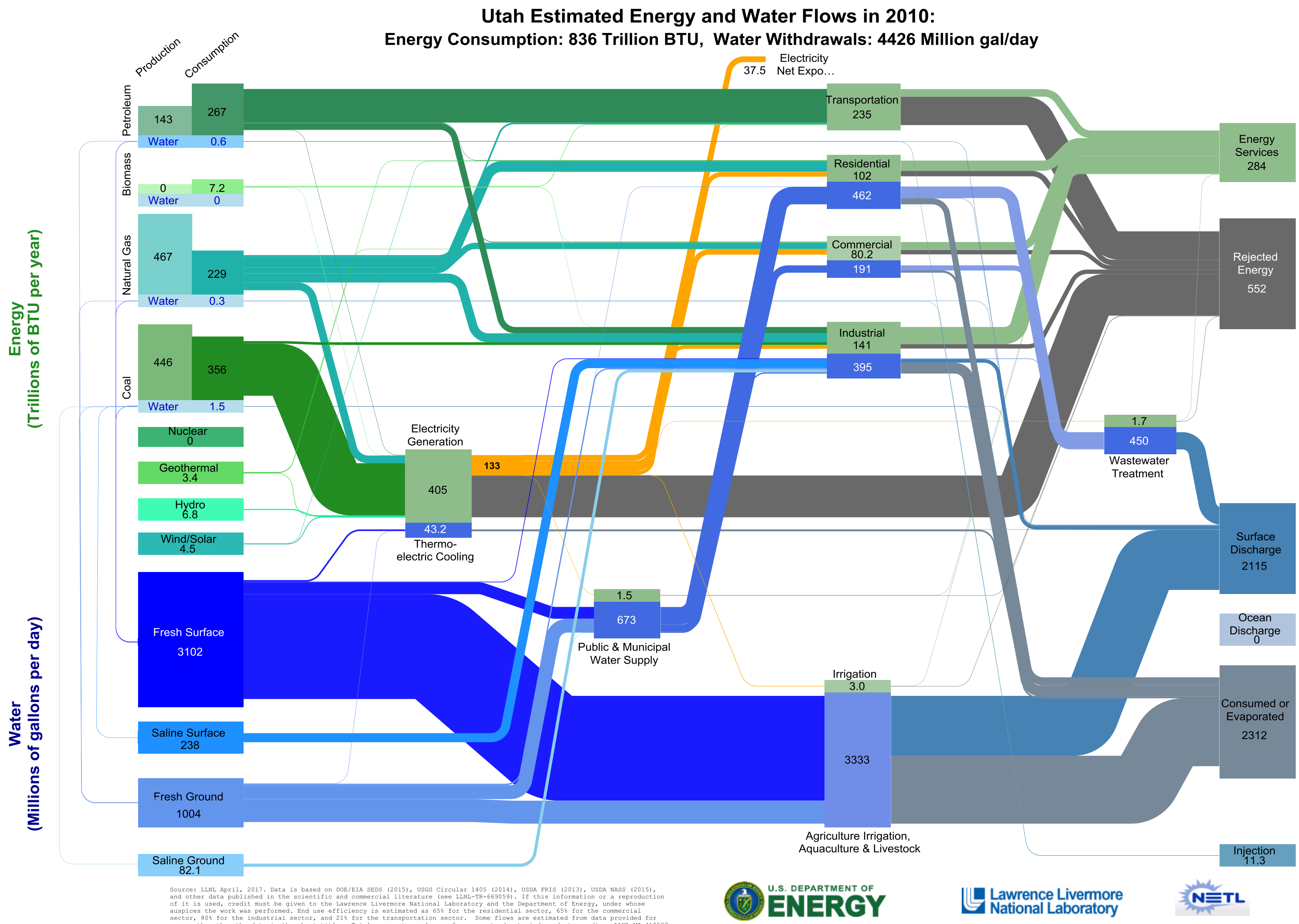
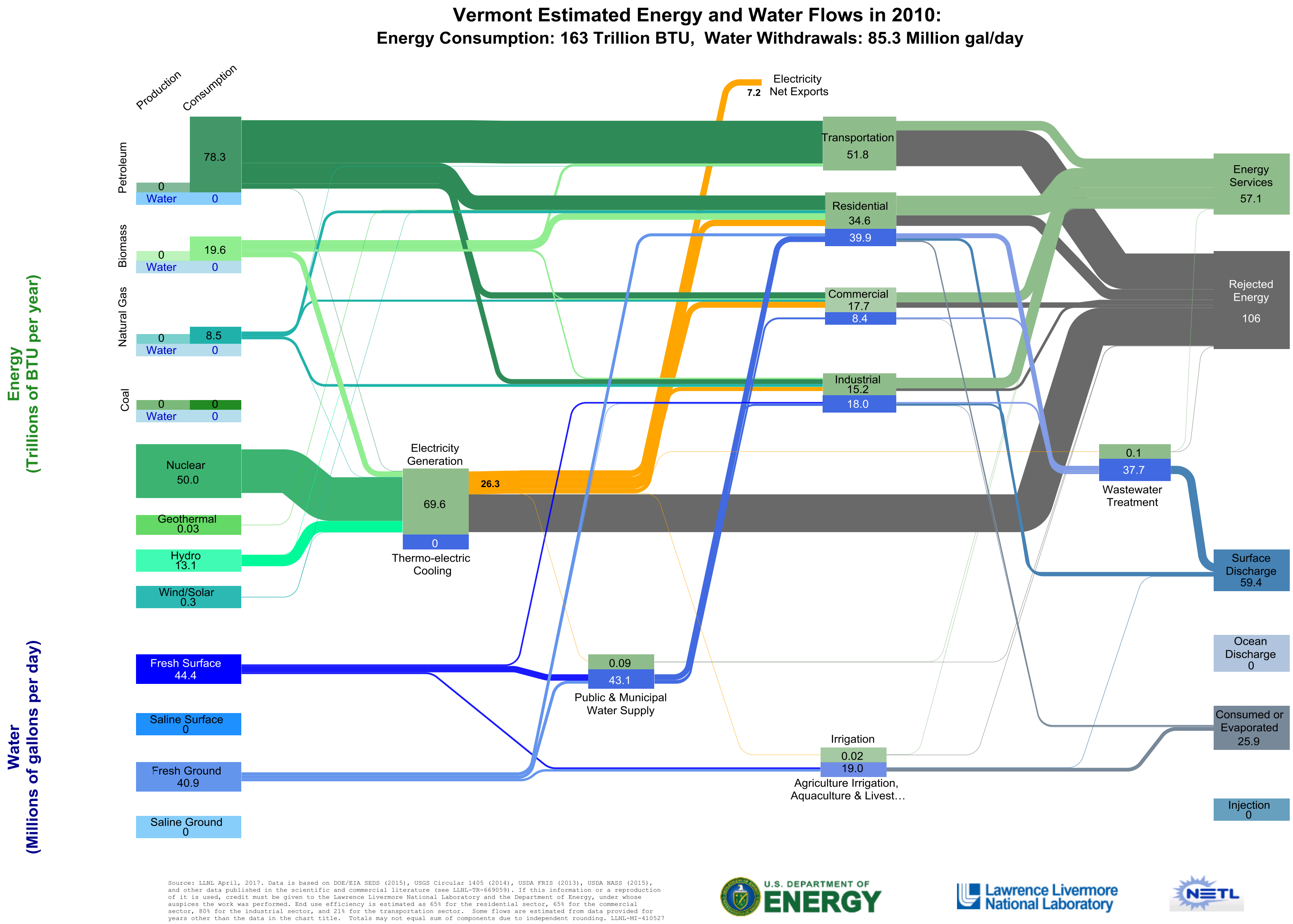


Figure 3-45 - Hybrid Energy-Water Sankey Diagram for Vermont



Source: LLNL April, 2017. Data is based on DOE/EIA SEDS (2015), USGS Circular 1405 (2014), USDA FRIS (2013), USDA NASS (2015), and other data published in the scientific and commercial literature (see LLNL-TR-669059). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Some flows are estimated from data provided for years other than the data in the chart title. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 3-46 - Hybrid Energy-Water Sankey Diagram for Virginia

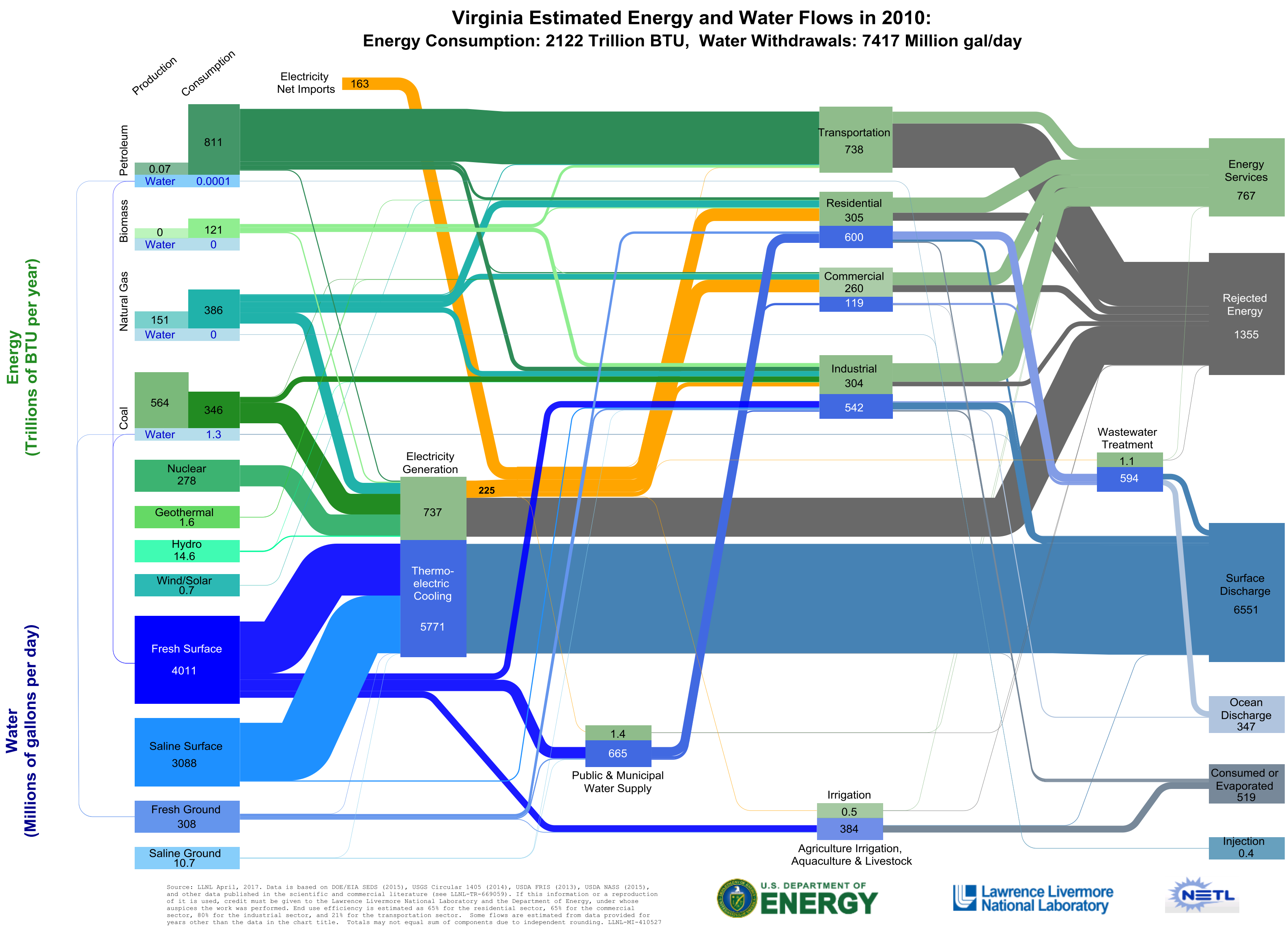


Figure 3-47 - Hybrid Energy-Water Sankey Diagram for Washington

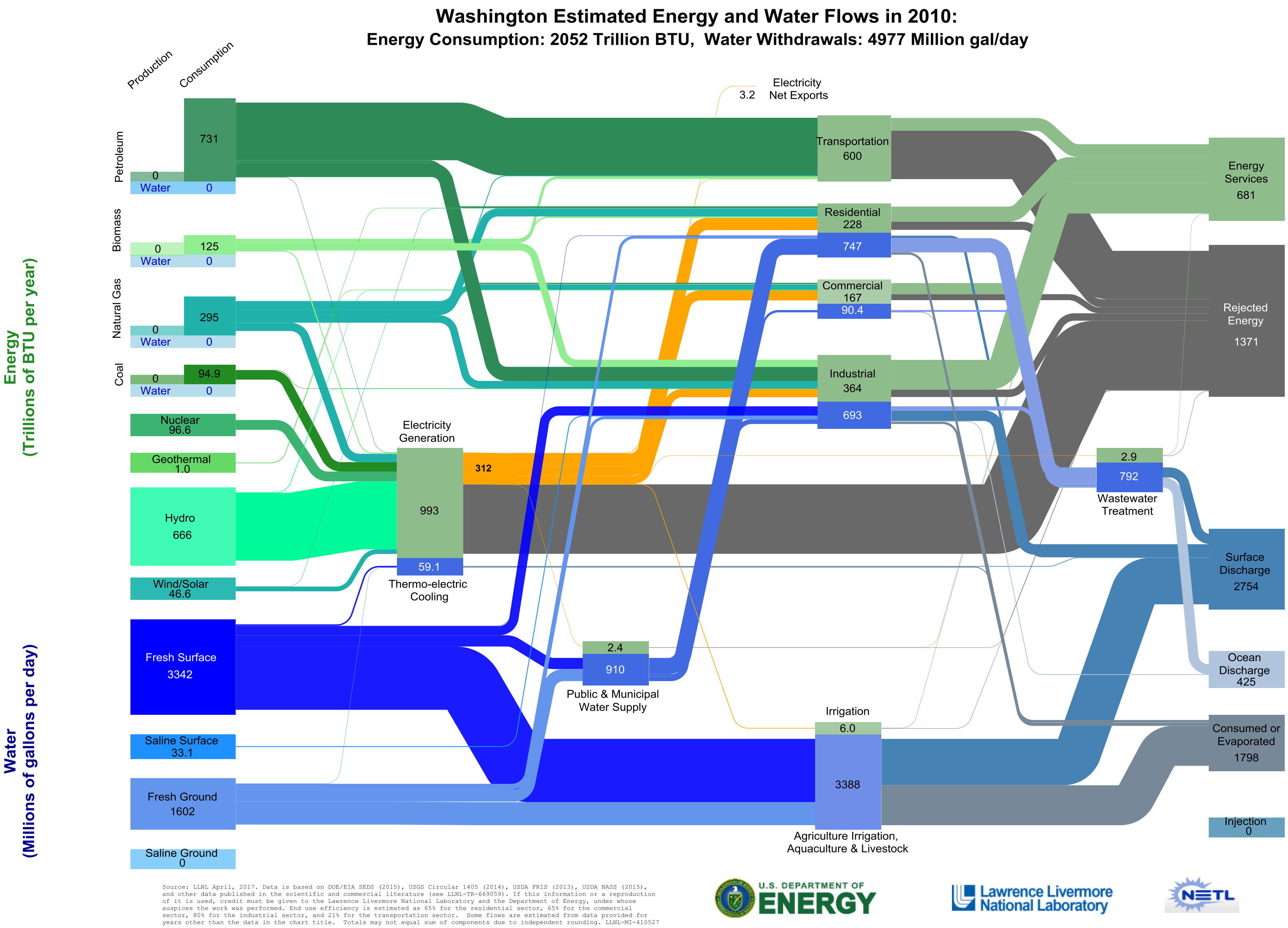


Figure 3-48 - Hybrid Energy-Water Sankey Diagram for West Virginia

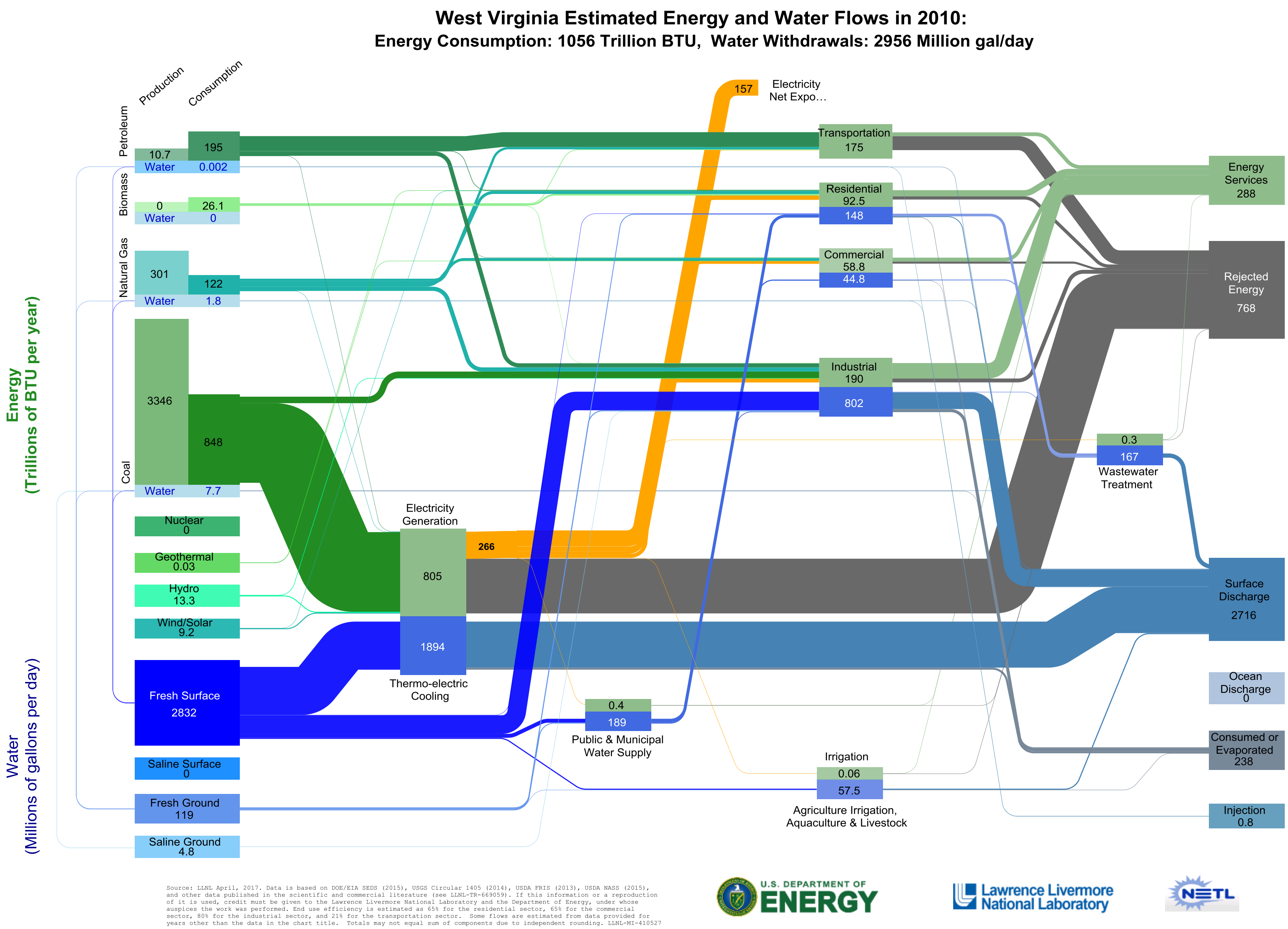


Figure 3-49 - Hybrid Energy-Water Sankey Diagram for Wisconsin

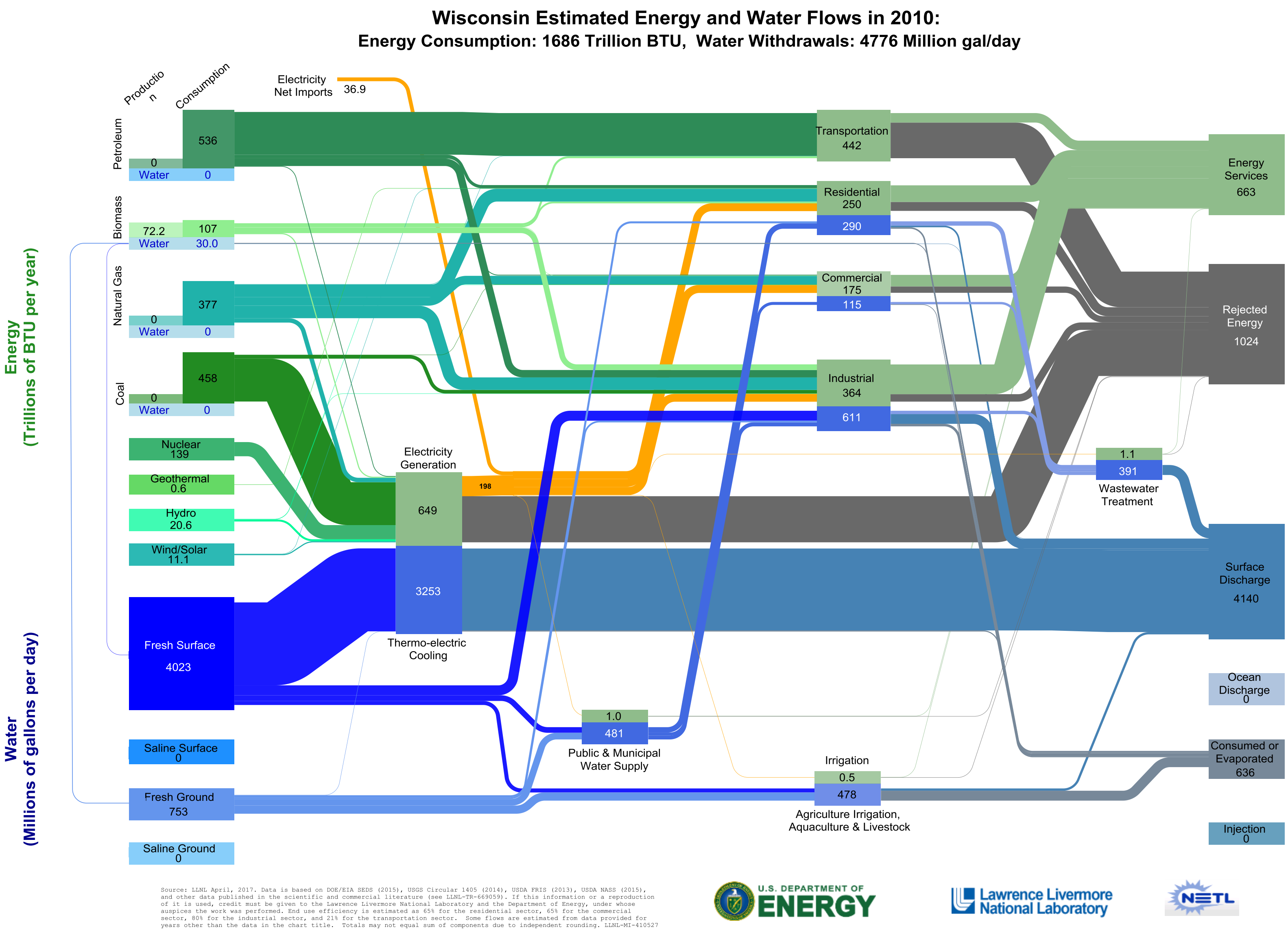
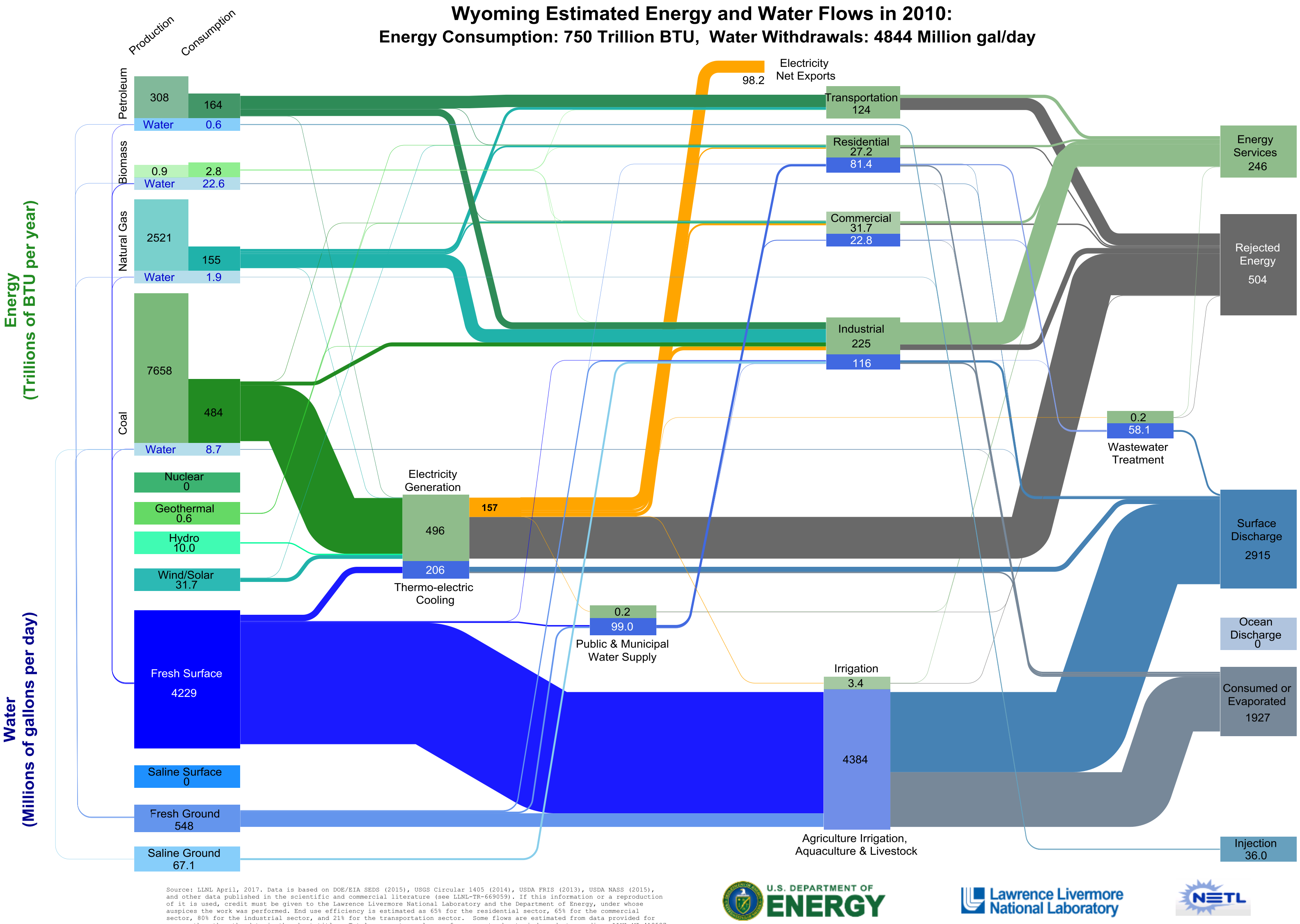


Figure 3-50 - Hybrid Energy-Water Sankey Diagram for Wyoming



4 State-Level Energy-Water Analysis (state-by-state rankings)

The creation of a full set of state-leve energy-water Sankey diagrams requires the fusion and normalization of energy and water data. This extensive analysis enables the comparison of energy and water use on a state-by-state basis. In this section, the states with the greatest and smallest energy and water use are highlighted. Because this analysis specifically targets the Energy-Water Nexus, the water intensity of energy and energy intensity of water are of greatest interest. With over 200 calculated values underlying each diagram, not all energy and water resources, conversions and disposition are analyzed. Rather, we focus on water use in the energy sector (water withdrawal and production associated with Oil and Natural Gas production, water withdrawal and consumption associated with electricity production and water use in bio-feedstock production) and energy used in the water sector (electricity used for agricultural water supply, municipal water treatment and wastewater treatment).

Extensive state-level energy and water are often correlated to the overall population of a state or the size of its energy infrastructure. Energy and water intensities, are, on the other hand, correlated to the mix of technologies and practices adopted within a state, as well as the extent of its energy production infrastructure and other economic activities. Energy and water intensities can be indicators of sustainability and may be improved through innovation and policy action.

This analysis does not consider energy and water intensities on a per-capita or economic activity (e.g. per unit GDP) basis. Such analysis would need to take into account extensive interstate trade in goods, services, energy and (occasionally) water, and is reserved for future work.

4.1 Water Use in the Energy Sector

4.1.1 Oil and Natural Gas Production

Water Withdrawn for Oil and Natural Gas Production

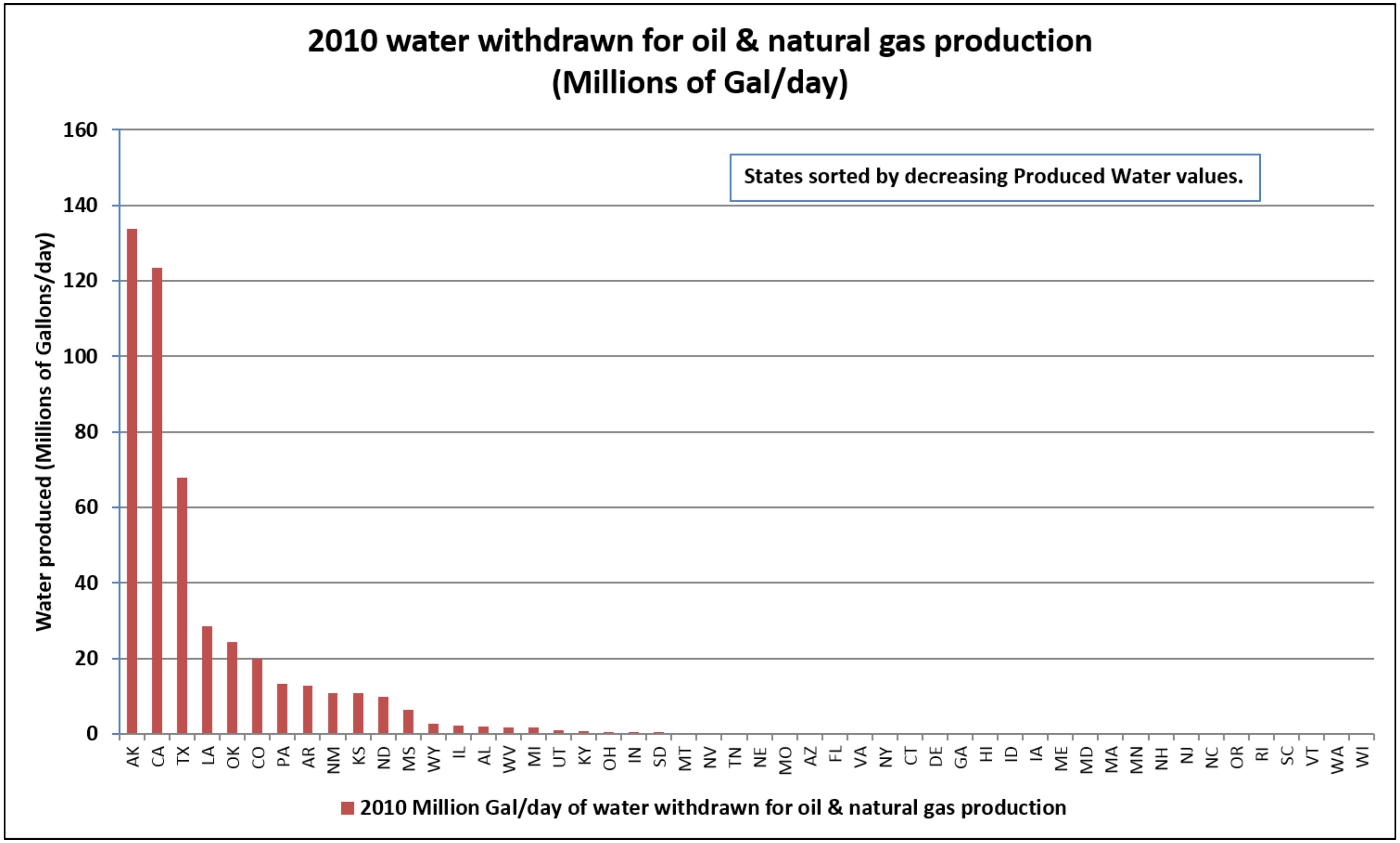
Water flood, steam flood, and hydraulic fracturing represent some of the major uses of water in the oil and natural gas industry. These operations enhance the quantity of hydrocarbons that can be extracted from subsurface, and may contribute to a state's water use in the production of fossil fuels. Most of the largest oil and natural gas producing states populate the top 10 list of the largest water users for oil and natural gas extraction. These include Texas, Alaska, California and Louisiana.

Table 4-1 – Top 10 States for 2010 Water Withdrawn for Oil and Natural Gas Production (MGD)
The top 10 states total 94% of water withdrawn for oil and natural gas

Live Link Database Variables	= LLB_OilW + LLB_GasW	
Data Type	2010 MGD of water withdrawn for oil & natural gas production	2010 Percent of water withdrawn for oil & natural gas production
State Totals	**475**	**100%**
TOP 10 STATES		
AK	133.7	28.1%
CA	123.5	26.0%
TX	67.8	14.3%
LA	28.6	6.0%
OK	24.4	5.1%
CO	19.8	4.2%
PA	13.2	2.8%
AR	12.7	2.7%
NM	10.8	2.3%
KS	10.7	2.3%
BOTTOM 5 STATES[1]		
MO	0.0349	0.007%
AZ	0.0244	0.005%
FL	0.0200	0.004%
VA	0.0001	0.00003%
NY	0.00004	0.00001%

[1] Note: CT, DE, GA, HI, ID, IA, ME, MD, MA, MN, NH, NJ, NC, OR, RI, SC, VT, WA, WI have values of zero

Figure 4-1 – Withdrawn Water for Oil and Natural Gas Production (MGD)



Water Withdrawal Intensity of Oil and Natural Gas Production

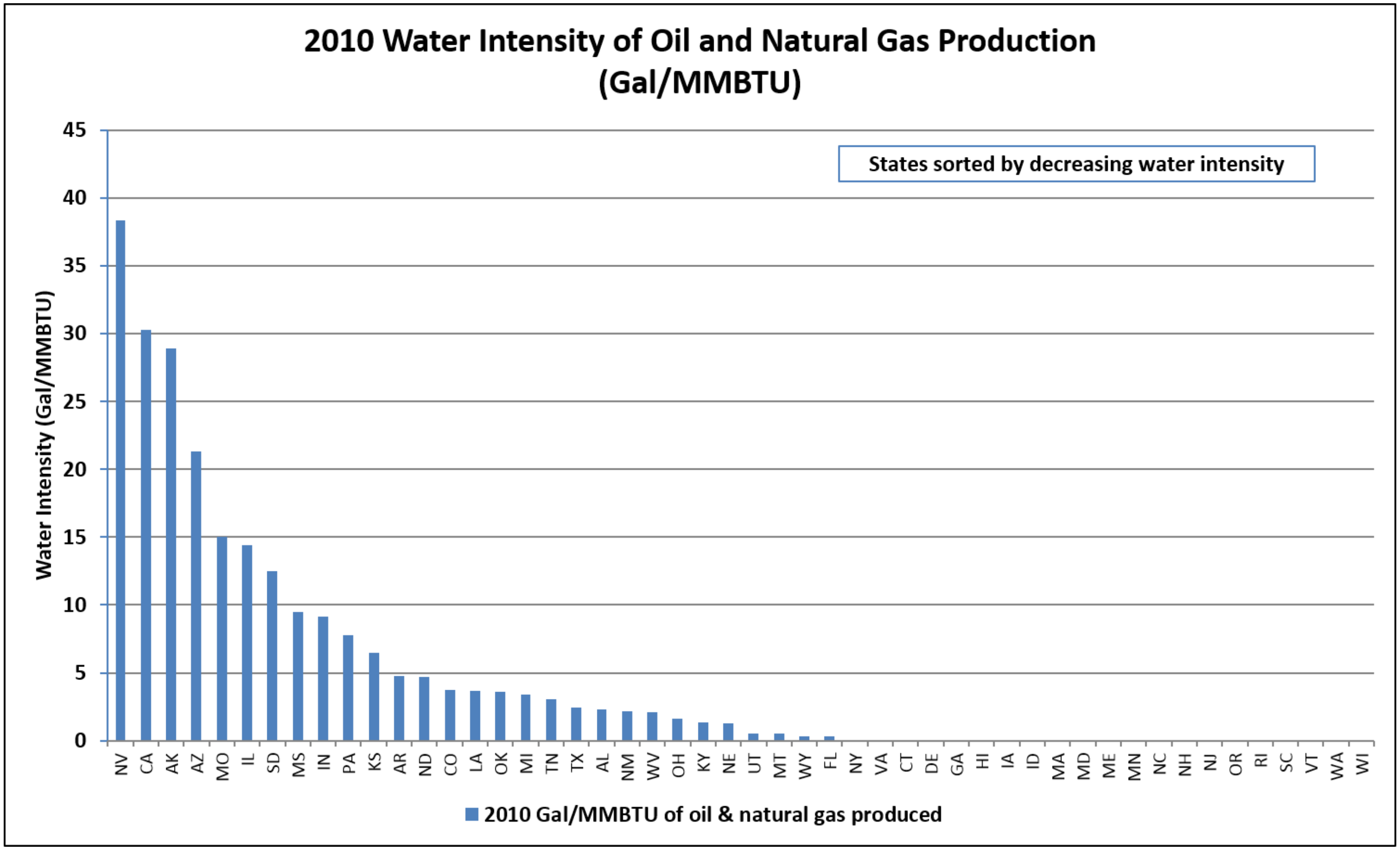
The water intensity of oil and natural gas production depends on the mix of practices used within a state. States that use water- or steam-flooding for a large fraction of their Oil and Natural Gas operations are near the top of this list.

Table 4-2 – Top 10 States for 2010 Water Intensity for Oil and Natural Gas Production (Gal/MMBTU). The top 10 states total 14% of the BTU of oil & natural gas produced

Live Link Database Variables	= 365*(LLB_OilW + LLB_GasW) /(LLB_OilProd + LLB_GasProd)	= (LLB_OilProd + LLB_GasProd)	
Data Type	2010 Gal/MMBTU of oil & natural gas produced	2010 TBTU of oil & natural gas produced	2010 Percent of U.S. total oil & natural gas production on a BTU basis
	Energy Weighted State Average	Total	Percent
	5.7	**30,554**	**100%**
TOP 10 STATES			
NV	38.4	2	0.0%
CA	30.3	1,487	4.9%
AK	28.9	1,688	5.5%
AZ	21.3	0	0.0%
MO	15.0	1	0.0%
IL	14.4	55	0.2%
SD	12.5	11	0.0%
MS	9.5	244	0.8%
IN	9.1	18	0.1%
PA	7.7	620	2.0%
BOTTOM 5 STATES[2]			
FL	0.3187	23	0.1%
NY	0.0004	39	0.1%
VA	0.0003	151	0.5%
MD	0.000	0.04	0.0001%
OR	0.000	1.4	0.0047%

[2] Note: CT, DE, GA, HI, IA, ID, MA, ME, MN, NC, NH, NJ, RI, SC, VT, WA, WI have values of zero

Figure 4-2 – Water Intensity of Oil and Natural Gas Production (Gal/MMBTU)



Produced Water from Oil and Natural Gas Extraction

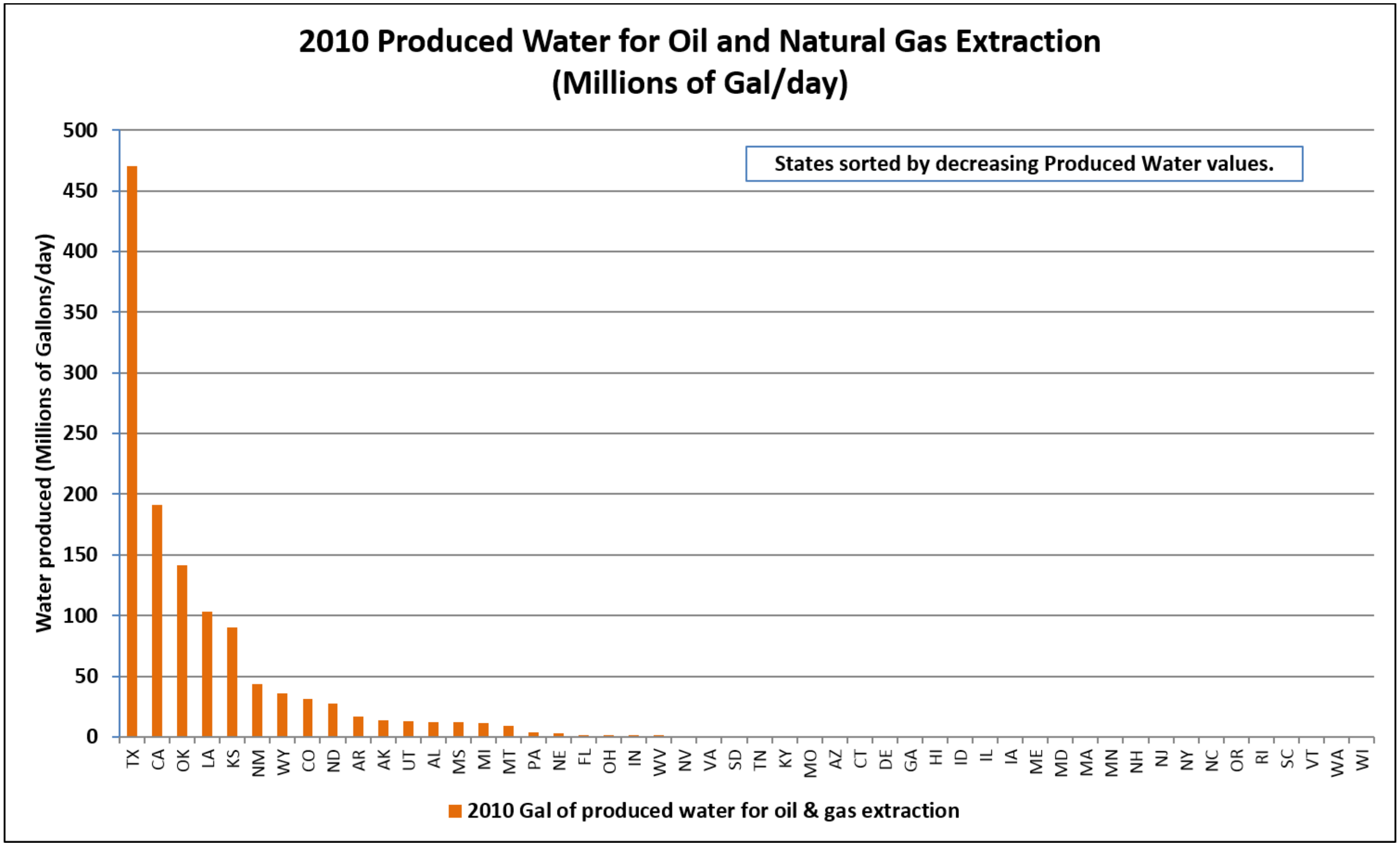
Produced water from completed oil and natural gas wells may include flowback water from hydraulic fracturing, and also includes water that exists alongside the oil and natural gas in the reservoir. Mature oil and natural gas fields may produce significant quantities of water because their hydrocarbons have been largely depleted, or because they are being stimulated with water and/or steam injection[3]. States that lead in the production of water from oil and natural gas wells are Texas, Oklahoma and California, all of which have large numbers of mature oil fields.

Table 4-3 – Top 10 States for 2010 Produced Water for Oil and Natural Gas Extraction (MGD)
The top 10 states total 93% produced water for oil & natural gas extraction

Live Link Database Variables	LLF{OilW_to_(OcDisch+ SurfDisch+Wcons+Winj)+ GasW_to_(OcDisch+ SurfDisch+Wcons+Winj)}	
Data Type	2010 MGD of produced water for oil & gas extraction	2010 Percent of produced water for oil & gas extraction
State Totals	**1,236**	**100%**
TOP 10 STATES		
TX	470.5	38.1%
CA	191.3	15.5%
OK	141.2	11.4%
LA	103.1	8.3%
KS	90.3	7.3%
NM	43.9	3.6%
WY	36.0	2.9%
CO	31.0	2.5%
ND	27.5	2.2%
AR	16.5	1.3%
BOTTOM 5 STATES[4]		
SD	0.3	0.02%
TN	0.2	0.01%
KY	0.1	0.01%
MO	0.04	0.003%
AZ	0.01	0.0009%

[3] There may be saline aquifers that are below the well casing contributing to produced water flow from day 1
[4] Note: CT, DE, GA, HI, ID, IL, IA, ME, MD, MA, MN, NH, NJ, NY, NC, OR, RI, SC, VT, WA, WI have values of zero

Figure 4-3 – Produced Water for Oil and Natural Gas Extraction (MGD)



4.1.2 Electricity Production

Water Withdrawn for Electricity Production

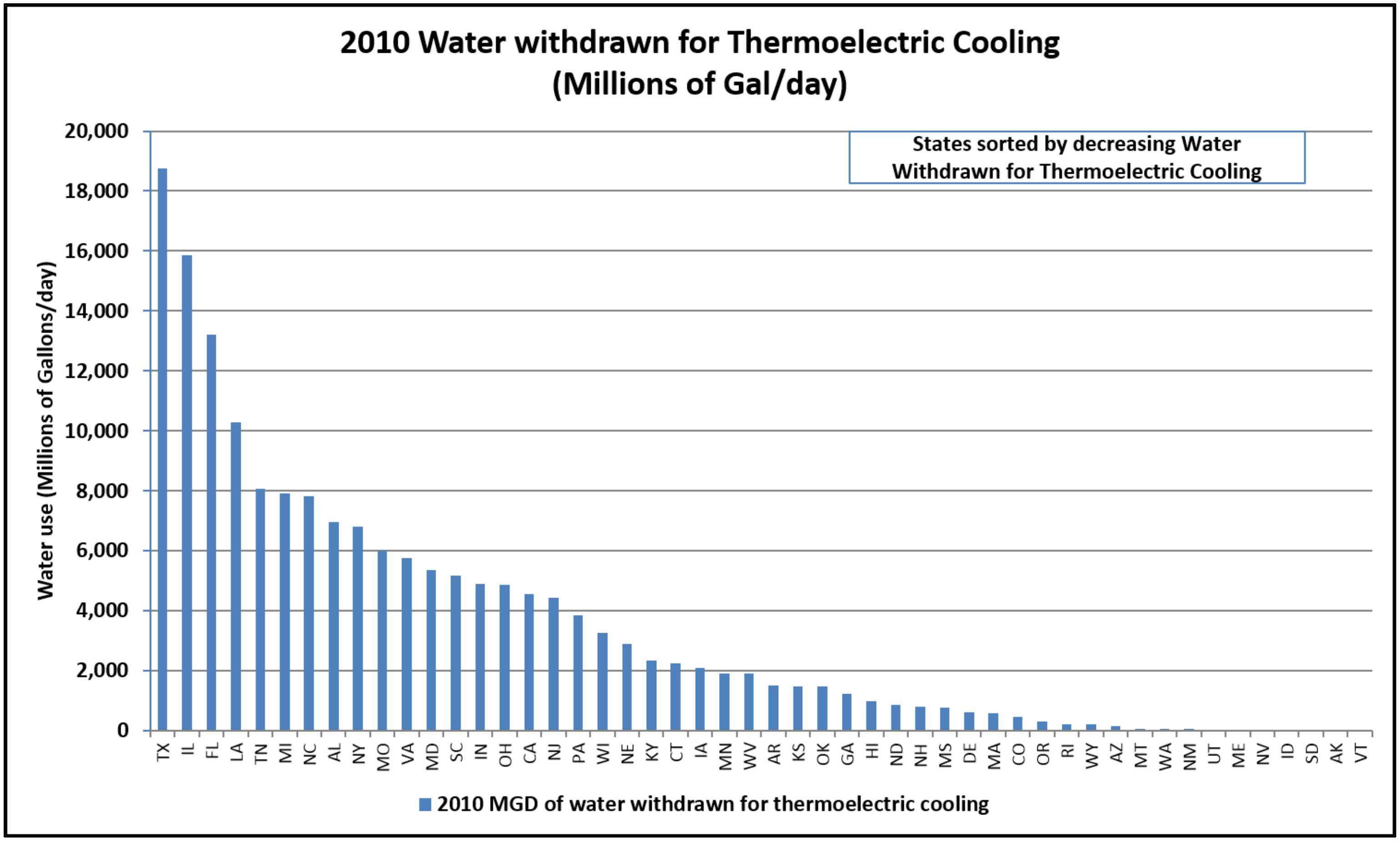
Because of the extremely high withdrawal intensity of once-through cooling (OTC) strategies, water withdrawal for electricity production is almost exclusively a function of the number of OTC power plants in a state. The states on the list below are populous and have a significant installed base of river- or ocean-sited power plants. With stricter fish protection standards and population shifts to drier western states without access to OTC-compatible water resources, most new capacity is being built with recirculating or dry cooling. The trend toward lower water withdrawals will continue into the future. Beyond the top 10 water withdrawing states for thermoelectric cooling, there are several more states with once-through cooled plants.

Table 4-4 – Top 10 States for 2010 Water Withdrawn for Thermoelectric Cooling (MGD)
The top 10 states total 60% withdrawn for thermoelectric cooling

Live Link Database Variables	LLB_ElecW	
Data Type	2010 MGD of water withdrawn for thermoelectric cooling	2010 Percent of water withdrawn for thermoelectric cooling
State Totals	**169,123**	**100%**
TOP 10 STATES		
TX	18,768	11.1%
IL	15,856	9.4%
FL	13,201	7.8%
LA	10,278	6.1%
TN	8,063	4.8%
MI	7,919	4.7%
NC	7,821	4.6%
AL	6,952	4.1%
NY	6,819	4.0%
MO	6,018	3.6%
BOTTOM 5 STATES[5]		
UT	43.2	0.03%
ME	39.2	0.02%
NV	31.9	0.02%
ID	16.5	0.01%
SD	0.2	0.0001%

[5] Note: AK, VT have values of zero

Figure 4-4 – Water Withdrawn for Thermoelectric Cooling (MGD)



Water Consumed for Electricity Production

Evaporation from cooling towers and ponds drives the consumption of water in thermoelectric cooling. OTC-equipped plants also drive evaporation from rivers and estuaries, although this effect may not be captured in the water withdrawal and consumption statistics. The states with the largest water consumption in the electric power sector are those with the largest fleets of tower-equipped power plants.

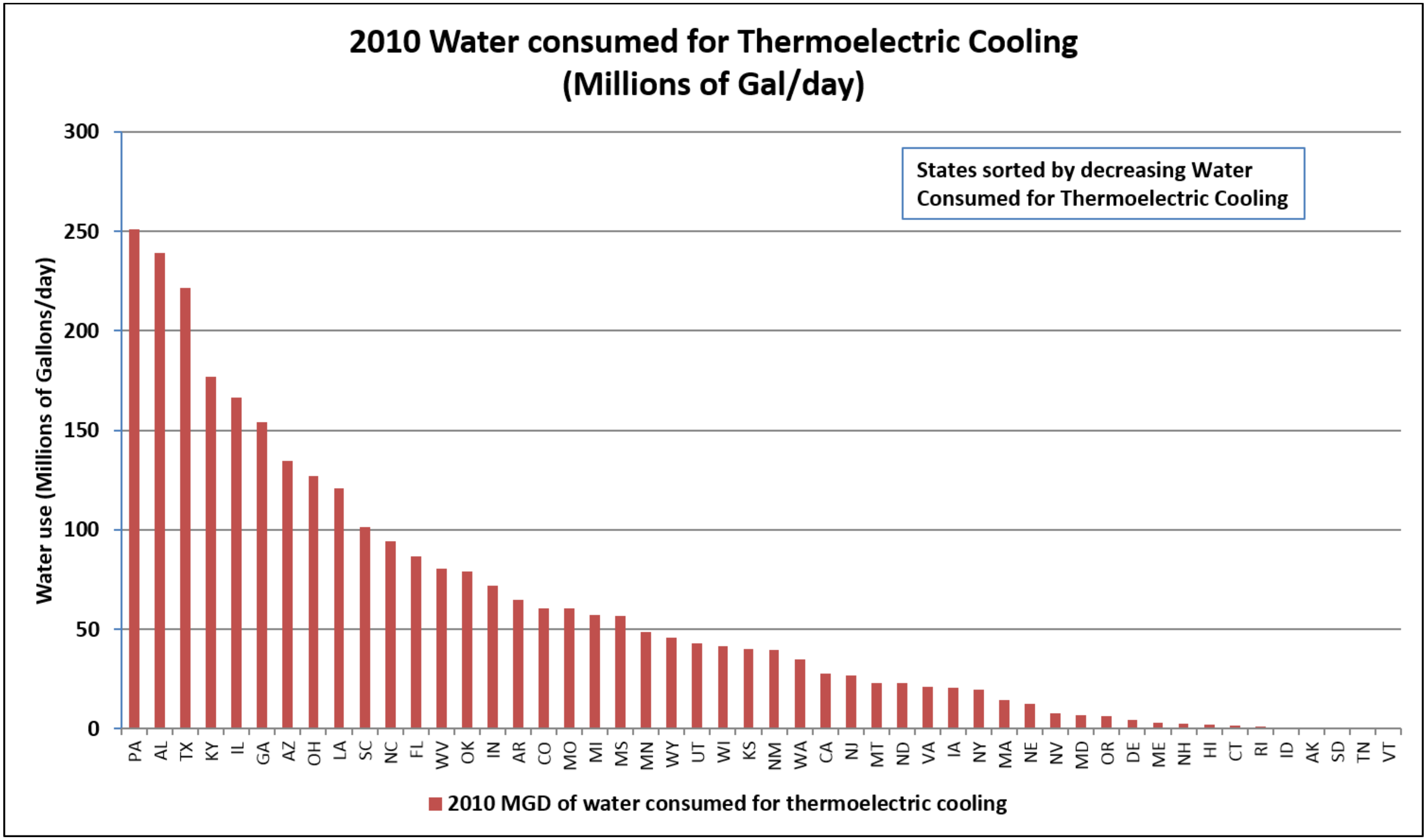
Table 4-5 – Top 10 States for 2010 Water Consumed for Thermoelectric Cooling (MGD)
The top 10 states total 58% water consumed for thermoelectric cooling

(States sorted by decreasing Water Withdrawn for Thermoelectric Cooling)

Live Link Database Variables	LLF_ElecW_to_Wcons	
Data Type	2010 MGD of water consumed for thermoelectric cooling	2010 Percent of water consumed for thermoelectric cooling
State Totals	**2,923**	**100%**
TOP 10 STATES		
PA	251.2	8.6%
AL	239.0	8.2%
TX	221.4	7.6%
KY	176.8	6.0%
IL	166.6	5.7%
GA	154.0	5.3%
AZ	134.6	4.6%
OH	127.2	4.3%
LA	120.7	4.1%
SC	101.6	3.5%
BOTTOM 5 STATES[6]		
NH	2.5	0.1%
HI	2.1	0.1%
CT	1.4	0.05%
RI	1.0	0.03%
ID	0.8	0.03%

[6] Note: AK, SD, TN, VT have values of zero

Figure 4-5 – Water Consumed for Thermoelectric Cooling (MGD)



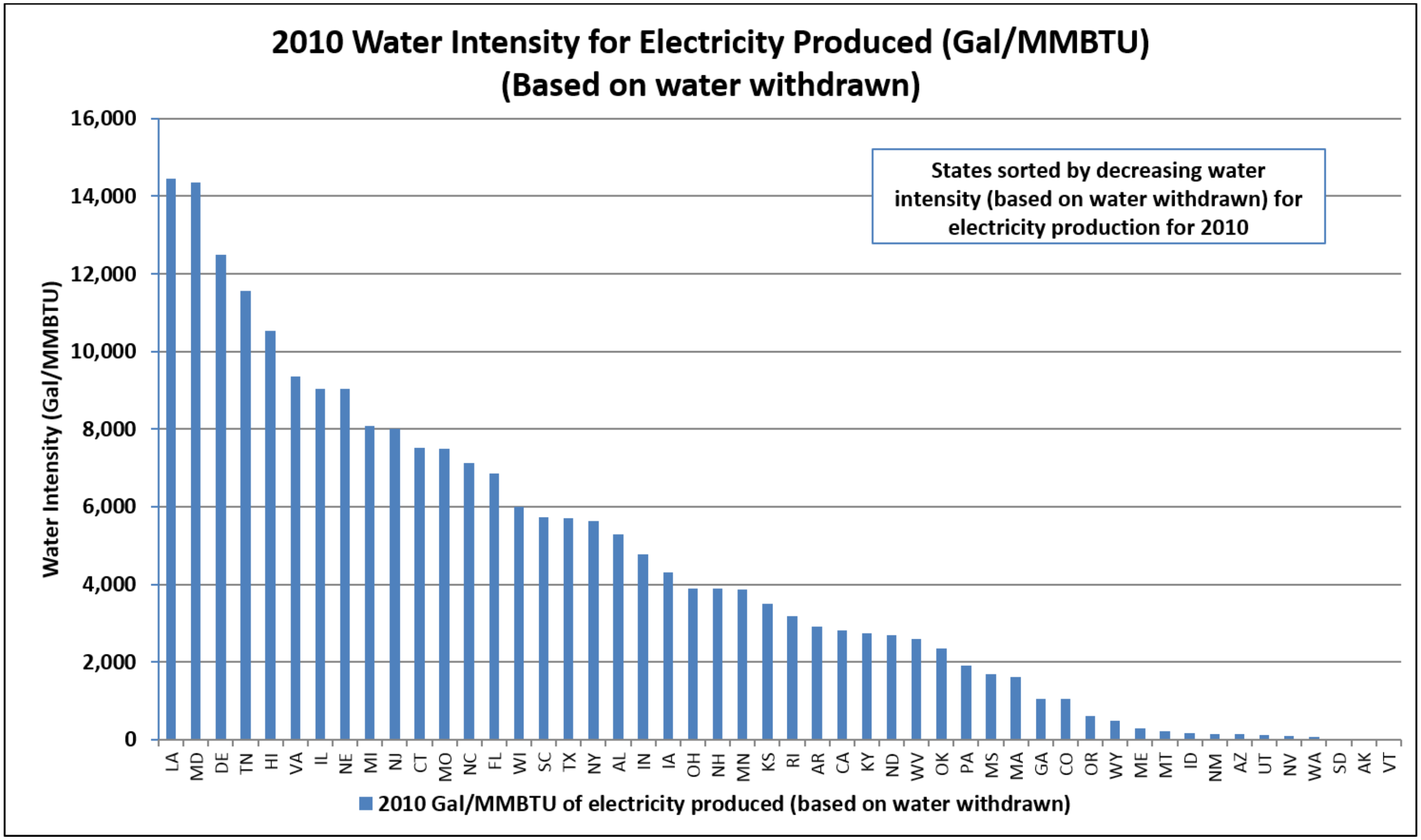
Water Intensity (based on water withdrawal) for Electricity Production

Again, because of the sharp disparity in water withdrawal between once-through-cooled and recirculating or other types of electricity production, the withdrawal intensity of electricity production depends largely on the fraction of power generation in a state that is dependent on once-through cooling. The water intensities reported here represent the gross water withdrawn in a state for power plant cooling divided by the total quantity of electricity generated in the state from all resources including dry-cooled and non-thermal (e.g. wind, solar, hydro) generators.

Table 4-6 – Top 10 States for 2010 Water Intensity (based on water withdrawal) of Electricity Production (Gal/MMBTU) The top 10 states total 18% of the electricity produced

Live Link Database Variables	365*LLB_ElecW / LLF_ElecGen_ to_ElecConn	LLF_ElecGen_ to_ElecConn	
Data Type	2010 Gal/MMBTU of electricity produced (based on water withdrawn)	2010 TBTU of electricity produced	2010 Percent of Total electricity produced
	Energy Weighted State Average	Total	Percent
	7,963	**12,791**	**100%**
TOP 10 STATES			
LA	14,442	259.8	2.0%
MD	14,366	136.1	1.1%
DE	12,495	17.7	0.1%
TN	11,555	254.7	2.0%
HI	10,538	34.2	0.3%
VA	9,353	225.2	1.8%
IL	9,051	639.4	5.0%
NE	9,030	117.0	0.9%
MI	8,085	357.5	2.8%
NJ	8,002	202.8	1.6%
BOTTOM 5 STATES			
NV	105.0	111.0	0.9%
WA	69.2	311.6	2.4%
SD	2.3	31.9	0.2%
AK	0.0	21.3	0.2%
VT	0.0	26.3	0.2%

Figure 4-6 – Water Intensity (based on water withdrawal) of Electricity Production (Gal/MMBTU)



Water Intensity (based on water consumption) for Electricity Production

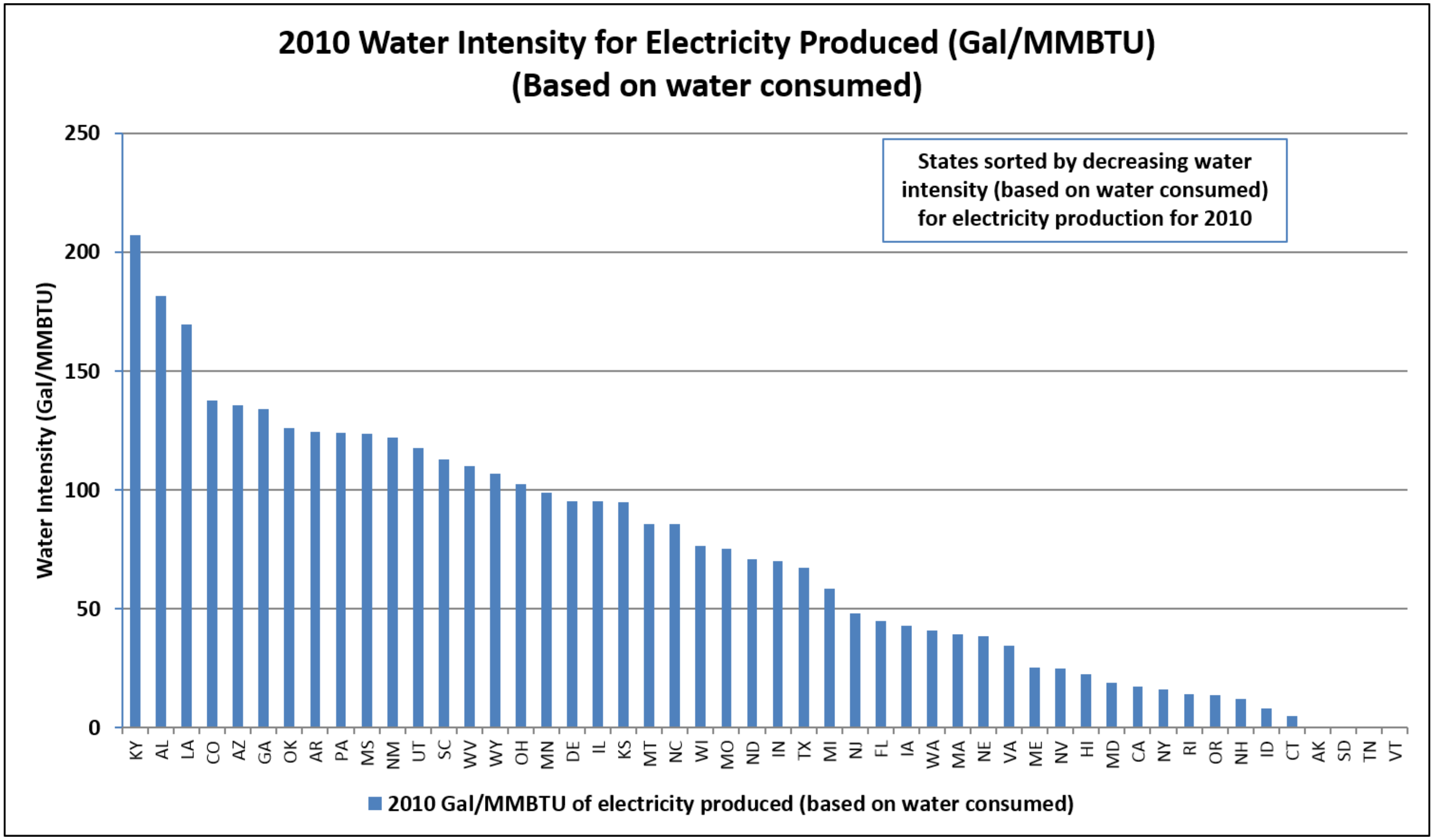
The water consumption intensity of electricity production depends on the ratio of once-through cooled to recirculating power plants. States whose power generation fleet includes a large fraction of evaporatively cooled plants lead the nation in water consumption in this sector. Those states include Kentucky, Alabama and Louisiana. The water intensities reported here represent the total water consumption in a state for power plant cooling divided by the total quantity of electricity generated in the state from all resources including dry-cooled and non-thermal (e.g. wind, solar, hydro) generators.

Table 4-7 – Top 10 States for 2010 Water Intensity (based on water consumption) for Electricity Production (Gal/MMBTU)

The top 10 states total 26% of the electricity produced

Live Link Database Variables	365* LLF_ElecW_to_Wcons / LLF_ElecGen_to_ElecConn	LLF_ElecGen_to_ElecConn	
Data Type	2010 Gal/MMBTU of electricity produced (based on water consumed)	2010 TBTU of electricity produced	2010 Percent of Total electricity produced
	Energy Weighted State Average	Total	Percent
	83.4	**12,791**	**100%**
TOP 10 STATES			
KY	207.1	311.6	2.4%
AL	181.7	480.1	3.8%
LA	169.6	259.8	2.0%
CO	137.7	160.9	1.3%
AZ	135.5	362.5	2.8%
GA	134.0	419.4	3.3%
OK	126.0	228.9	1.8%
AR	124.3	189.9	1.5%
PA	124.0	739.5	5.8%
MS	123.5	167.7	1.3%
BOTTOM 5 STATES			
CT	4.8	108.3	0.8%
AK	0.0	21.3	0.2%
SD	0.0	31.9	0.2%
TN	0.0	254.7	2.0%
VT	0.0	26.3	0.2%

Figure 4-7 – Water Intensity (based on water consumed) for Electricity Production (Gal/MMBTU)



4.1.3 Bio-Feedstock Production

Water Withdrawn for Bio-Feedstock Production

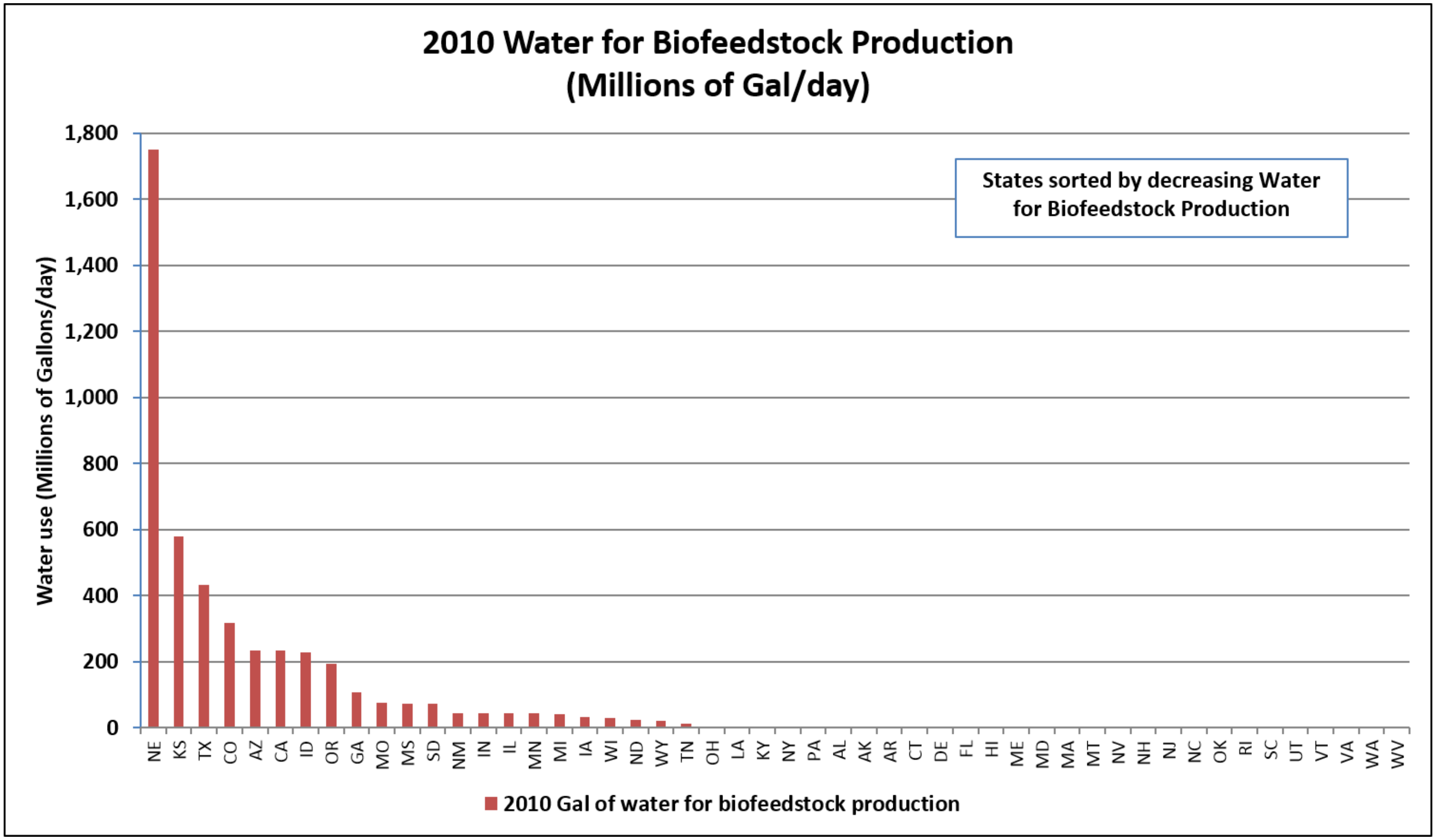
Water withdrawal for biofuel feedstock (largely corn) production is driven by both the magnitude of biomass produced as well as the extent of irrigation. Nebraska is the largest irrigator of biofuel crops, followed by Kansas and Texas. Large biofuel producers such as Iowa and Wisconsin are absent from the list of top water uses because their biomass crops are largely irrigated by rainfall.

Table 4-8 – Top 10 States for 2010 Water Withdrawn for Bio-feedstock Production (MGD)
The top 10 states total 89% of bio-feedstock water supplied

Live Link Database Variables	= LLB_BioW	
Data Type	2010 MGD of water for bio-feedstock production	2010 Percent of Total bio-feedstock water supplied
State Totals	**4648**	**100%**
TOP 10 STATES		
NE	1752	37.7%
KS	580	12.5%
TX	433	9.3%
CO	318	6.8%
AZ	235	5.1%
CA	234	5.0%
ID	229	4.9%
OR	193	4.2%
GA	108	2.3%
MO	76	1.6%
BOTTOM 5 STATES[7]		
OH	2.1	0.04%
LA	1.1	0.02%
KY	0.7	0.01%
NY	0.2	0.004%
PA	0.1	0.001%

[7] Note: AL, AK, AR, CT, DE, FL, HI, ME, MD, MA, MT, NV, NH, NJ, NC, OK, RI, SC, UT, VT, VA, WA, WV have values of zero

Figure 4-8 – Water Withdrawn for Bio-feedstock Production (MGD)



Water Intensity of Bio-Feedstock Production

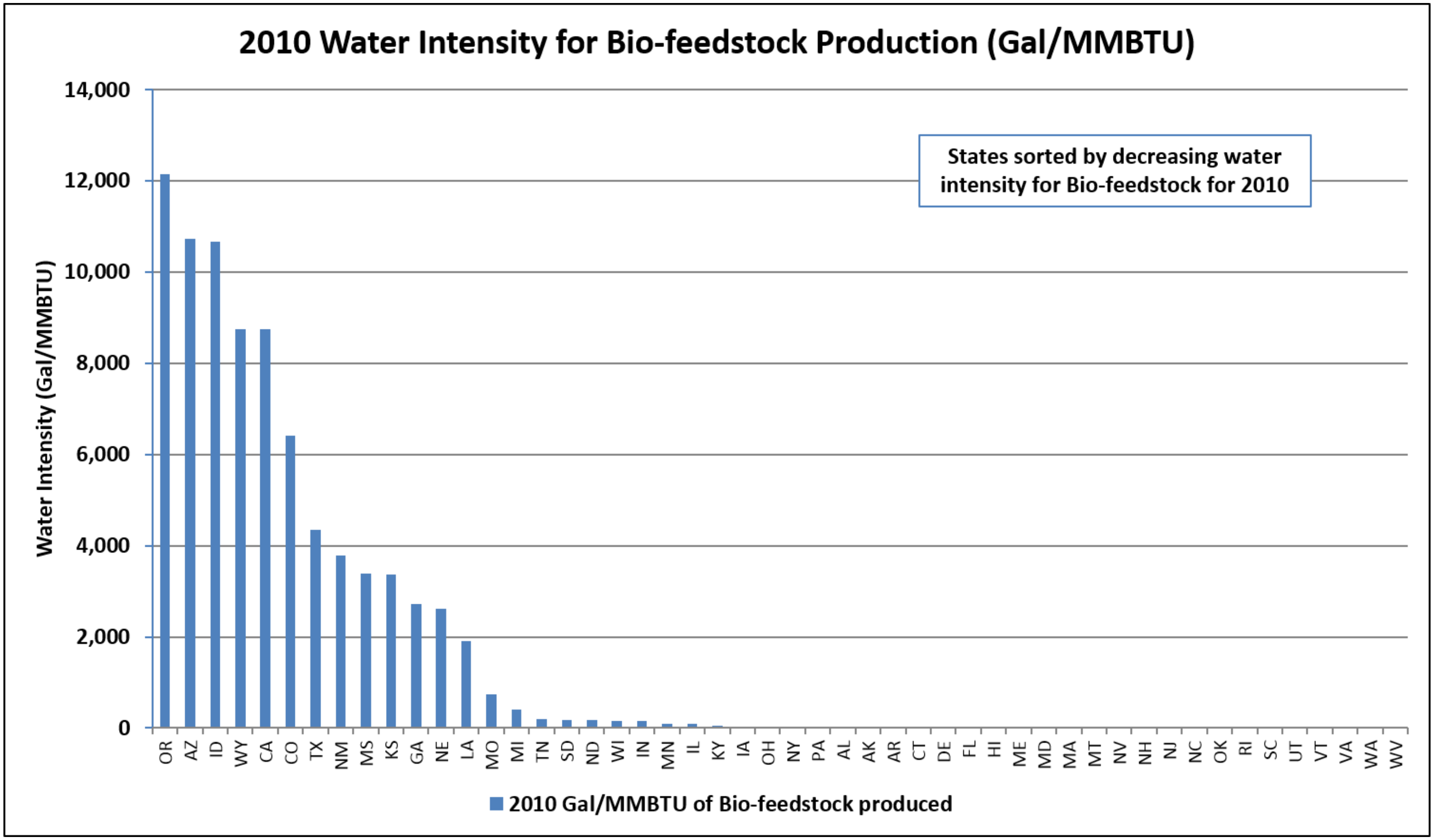
The water intensity of biomass production, as depicted here is calculated from the water used to irrigate biomass crops divided by the total quantity of biomass crops produced in the state. It is therefore driven largely by the fraction of the biomass crop within a state that is irrigated. Oregon, Arizona, Idaho, Wyoming and California all have high water intensity of bio-feedstock production because, in these arid western states, local precipitation is insufficient to produce a bioenergy crop during the growing season.

Table 4-9 – Top 10 States for 2010 Water Intensity of Bio-Feedstock Production (Gal/MMBTU)
The top 10 states total 9% of the BTU of bio feedstock produced

Live Link Database Variables	= (365*LLB_BioW) / LLB_BioProd	= LLB_BioProd	
Data Type	2010 Gal/MMBTU of Bio-feedstock produced	2010 TBTU of Bio-feedstock produced	2010 Percent of BTU of Bio-feedstock produced
State Average	**1,636**	**36.8**	
TOP 10 STATES			
OR	12,157	5.8	0.3%
AZ	10,739	8.0	0.4%
ID	10,668	7.8	0.4%
WY	8,740	0.9	0.1%
CA	8,740	9.8	0.5%
CO	6,407	18.1	1.0%
TX	4,357	36.3	2.0%
NM	3,779	4.4	0.2%
MS	3,387	7.8	0.4%
KS	3,358	63.0	3.4%
BOTTOM 5 STATES[8]			
KY	48	5.1	0.3%
IA	24	504.1	27.4%
OH	14	54.9	3.0%
NY	4	15.5	0.8%
PA	1	14.6	0.8%

[8] Note: AL, AK, AR, CT, DE, FL, HI, ME, MD, MA, MT, NV, NH, NJ, NC, OK, RI, SC, UT, VT, VA, WA, WV have values of zero

Figure 4-9 – Water Intensity of Bio-feedstock Production (Gal/MMBTU)



4.2 Energy Use in the Water Sector

4.2.1 Agricultural Water Pumping

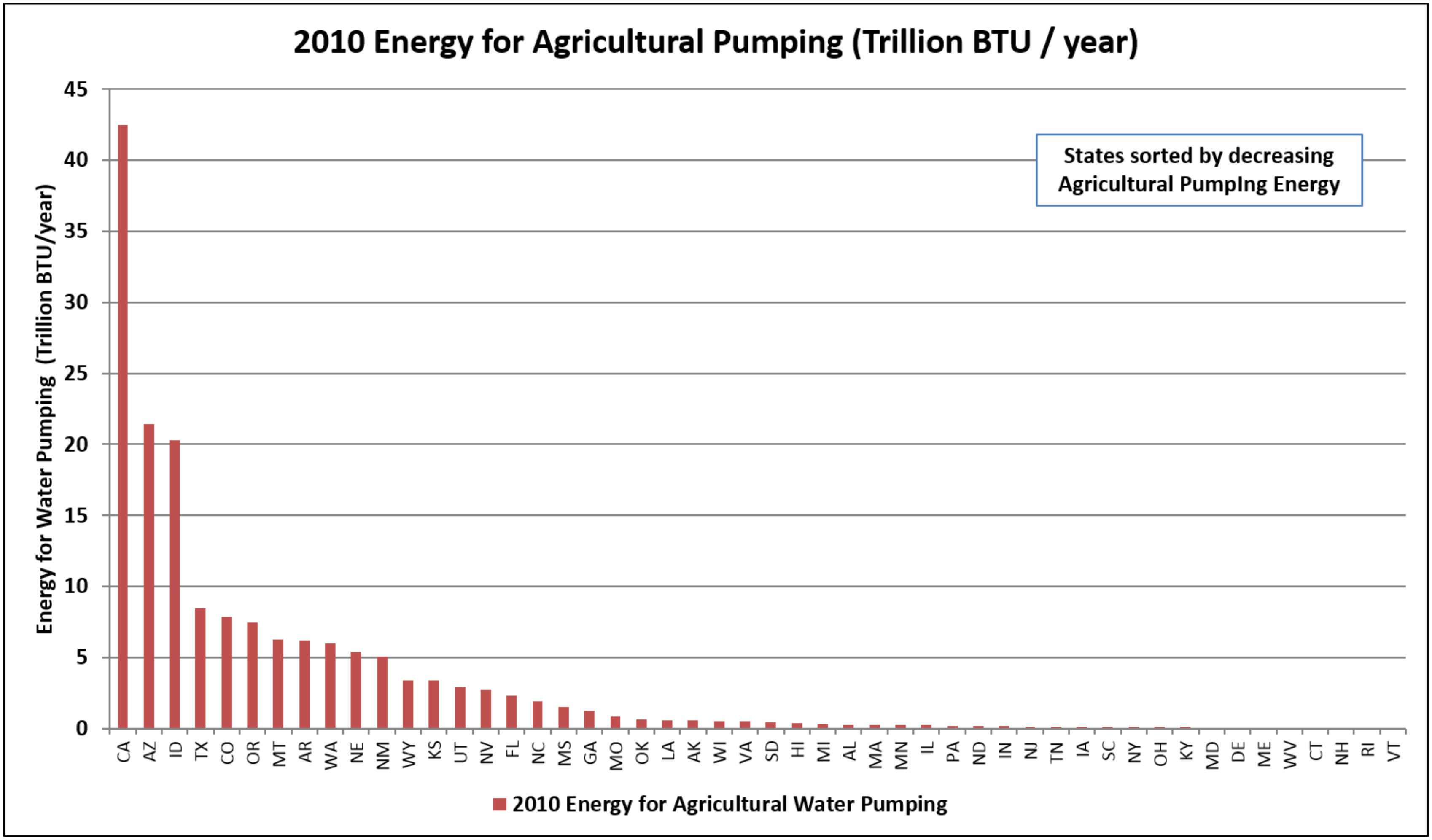
Energy Use for Agricultural Water Pumping

California uses the largest quantity of energy for delivering water to its agriculture industry. California is the largest agricultural state, and it has a relatively high energy intensity of water delivery. Other states that consume large amounts of energy for agricultural water pumping include Arizona (whose energy intensity is the highest), and Idaho. In fact, the top 10 states for energy consumed by agricultural water pumping are all Western states where farming operations occur in arid regions and large quantities of irrigation water are required.

Table 4-10 – Top 10 States for 2010 Energy for Agricultural Water Pumping
The top 10 states total 80% of energy for agricultural water pumping

Live Link Database Variables	= LLB_AgE	
Data Type	2010 Energy for Agricultural Water Pumping (TBTU)	2010 % Energy for Agricultural Water Pumping
State Totals	**164**	**100%**
TOP 10 STATES		
CA	42.5	25.9%
AZ	21.4	13.0%
ID	20.3	12.4%
TX	8.5	5.2%
CO	7.9	4.8%
OR	7.5	4.6%
MT	6.3	3.8%
AR	6.2	3.8%
WA	6.0	3.6%
NE	5.4	3.3%
BOTTOM 5 STATES		
WV	0.06	0.04%
CT	0.05	0.03%
NH	0.02	0.02%
RI	0.02	0.01%
VT	0.02	0.01%

Figure 4-10 – Energy for Agricultural Pumping (Trillion BTU/year)



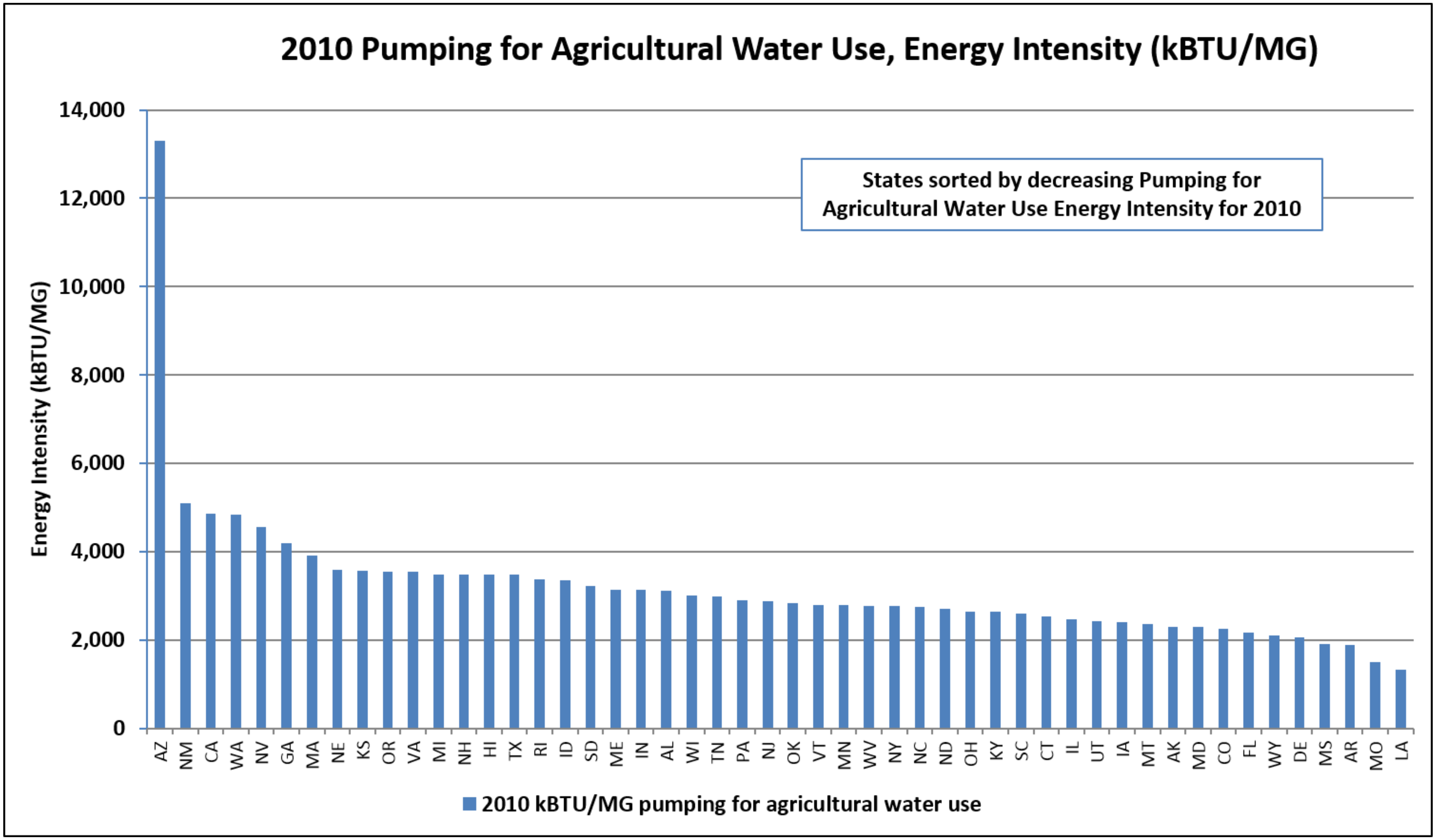
Energy Intensity of Agricultural Water Pumping

Arizona has the highest energy intensity for agricultural water pumping. This energy intensity is due to the large use of energy for water conveyance through Arizona (chiefly the Central Arizona Project). New Mexico and California also have high energy intensities. Massachusetts, a northeastern outlier among a list of large western and agricultural states, appears because FRIS indicates that sprinkler pressure for irrigation is much higher there than in most other states.

Table 4-11 – Top 10 States for 2010 Energy Intensity for Pumping for Agricultural Water Use
The top 10 states total 41% of water supplied

Energy Intensity	2010 Agricultural Water Pumping Data		
Live Link Database Variables	= 1e9*LLB_AgE/ (365*LLB_AgW)	= 365*LLB_AgW	
Data Type	2010 kBTU/MG pumping for agricultural water use	2010 MG of pumping for agricultural water use	2010 Percent of Total agricultural water use
	National Mass Avg.	Total Ag water	National & State %
	3,684	**44,556,236**	**100%**
TOP 10 STATES			
AZ	13,310	1,609,244	3.6%
NM	5,108	987,967	2.2%
CA	4,852	8,753,860	19.6%
WA	4,833	1,236,554	2.8%
NV	4,557	594,322	1.3%
GA	4,197	295,476	0.7%
MA	3,922	69,456	0.2%
NE	3,584	1,500,546	3.4%
KS	3,566	944,677	2.1%
OR	3,539	2,114,542	4.7%
BOTTOM 5 STATES			
DE	2,068	37,486	0.1%
MS	1,905	792,561	1.8%
AR	1,880	3,294,596	7.4%
MO	1,499	576,733	1.3%
LA	1,326	454,752	1.0%

Figure 4-11 – Pumping for Agricultural Water Use, Energy Intensity (kBTU/MG)



4.2.2 Public Water Supply

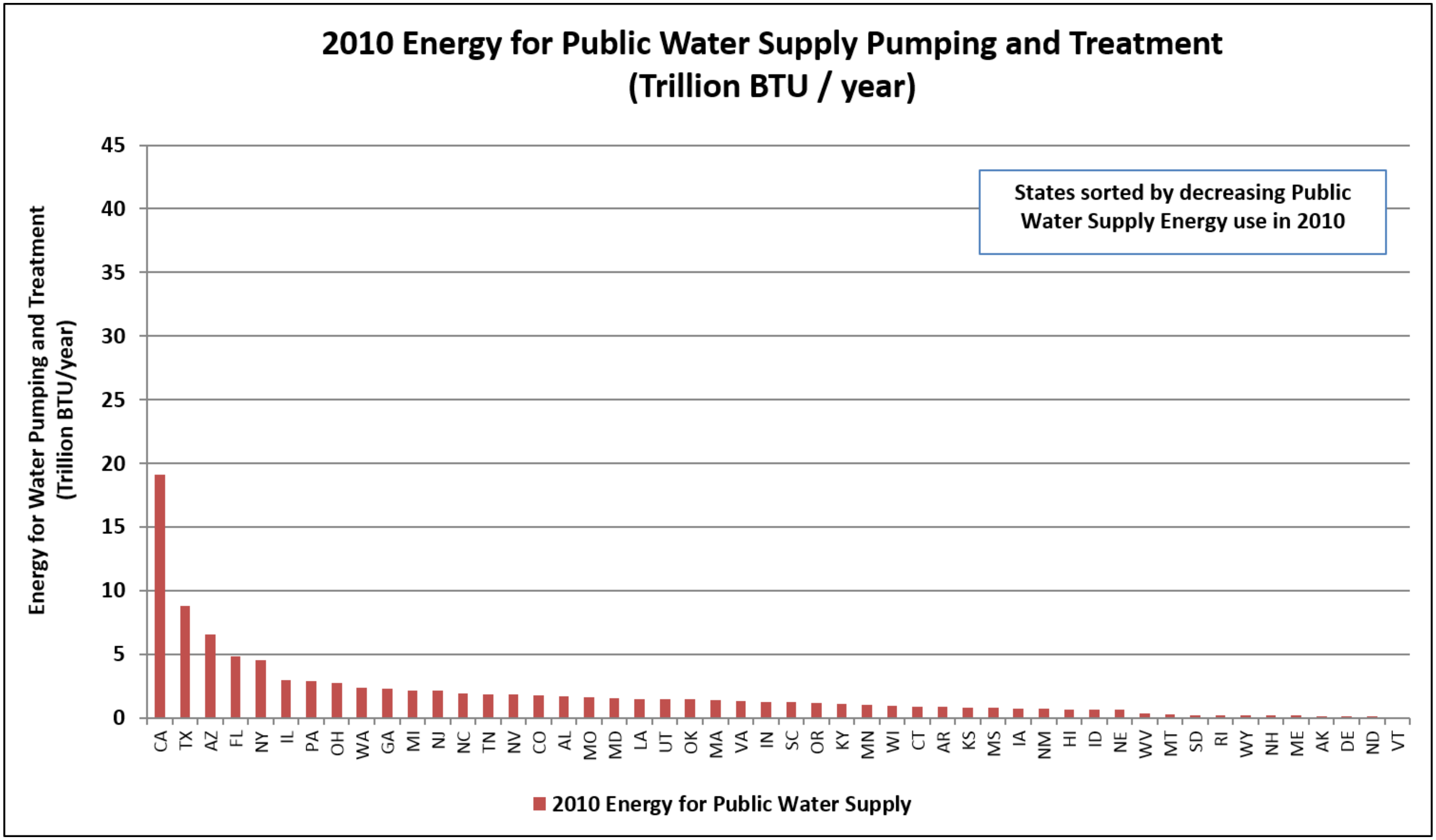
Energy Use for Public Water Supply

California uses the largest quantity of energy for withdrawing, treating and delivering water to residential, commercial and industrial customers. California is the most populous state, and is highly urbanized, therefore it is no surprise that California dominates energy consumption for municipal wastewater treatment. California also has a relatively high energy intensity for public water supply (see below). The remaining states in this list represent the other states with large populations served by municipal suppliers.

Table 4-12 – Top 10 States for 2010 Energy for Public Water Supply
The top 10 states total 59% of energy for public water supply

Live Link Database Variables	= LLB_PSE	
Data Type	2010 Energy for Public Water Supply (TBTU)	2010 % Energy for Public Water Supply
State Totals	**97.1**	**100%**
TOP 10 STATES		
CA	19.2	19.7%
TX	8.8	9.1%
AZ	6.5	6.7%
FL	4.8	5.0%
NY	4.5	4.7%
IL	3.0	3.1%
PA	2.9	3.0%
OH	2.7	2.8%
WA	2.4	2.5%
GA	2.3	2.4%
BOTTOM 5 STATES		
ME	0.2	0.2%
AK	0.2	0.2%
DE	0.2	0.2%
ND	0.1	0.1%
VT	0.1	0.1%

Figure 4-12 – Energy for Public Water Supply Pumping and Treatment (Trillion BTU/year)



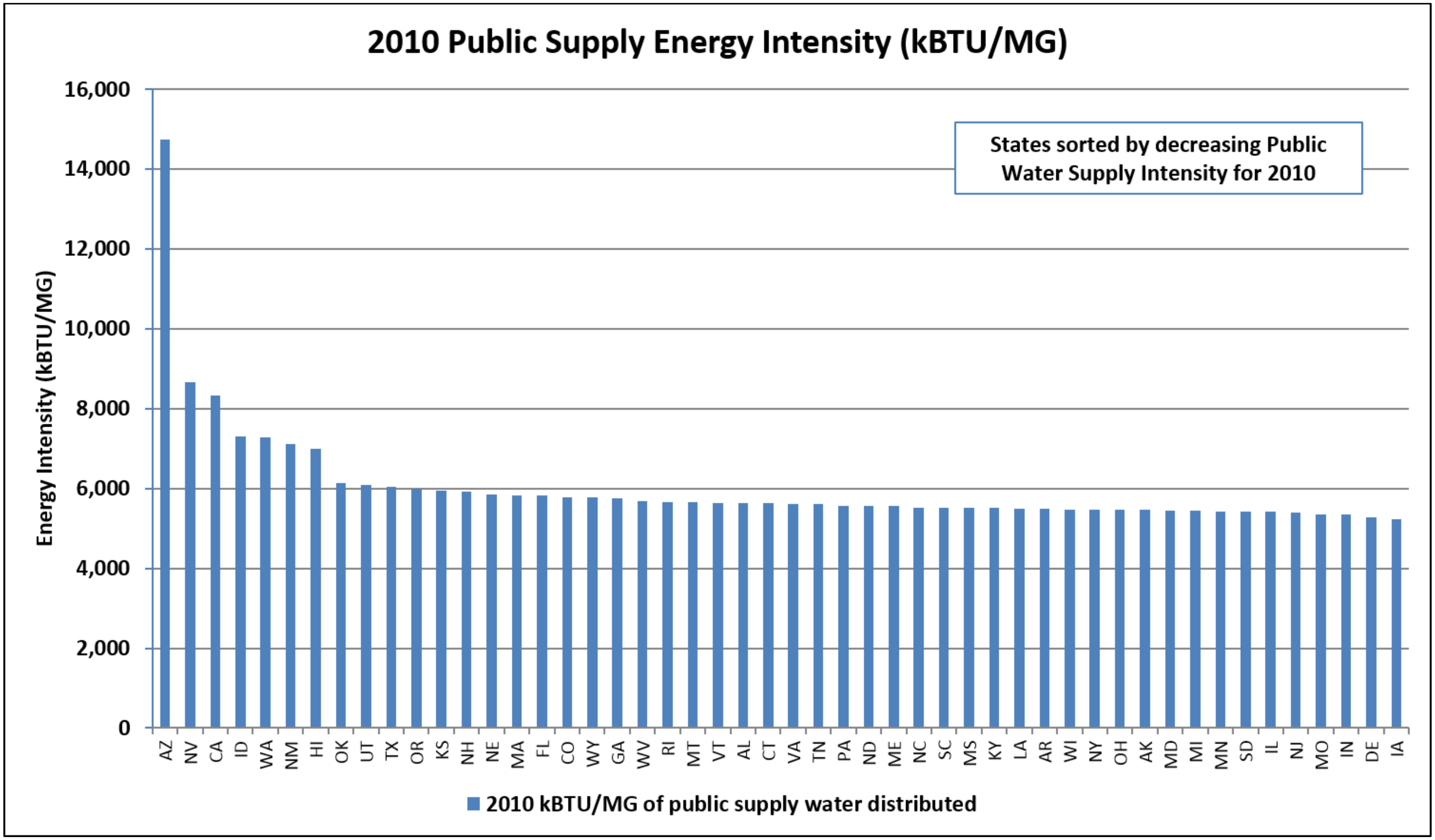
Energy Intensity of Public Supply

The energy intensity of public supply depends on the mixture of surface and groundwater in public supply, the depth to groundwater, and the amount of long-distance conveyance of water employed by a state. Arizona, Nevada and California have the highest energy intensity for municipal water supply and treatment because they all employ a significant amount of energy in conveying water. The other states on this list are representative of arid, western states.

Table 4-13 – Top 10 States for 2010 Energy Intensity for Public Water Supply
The top 10 states total 37% of water supplied

Energy Intensity	2010 Data Sorted by decreasing PS Energy Intensity		
Live Link Database Variables	= 1000000000 *LLB_PSE /(365*LLB_PSW)	= 365*LLB_PSW	
Data Type	2010 kBTU/MG of public supply water distributed	2010 MG of public supply water distributed	2010 Percent of Total public supply water distributed
	National Mass Avg.	Total PS water	National & State %
	6,432	**15,094,787**	**100%**
TOP 10 STATES			
AZ	14,752	442,898	2.9%
NV	8,661	211,996	1.4%
CA	8,330	2,299,033	15.2%
ID	7,301	87,089	0.6%
WA	7,272	332,015	2.2%
NM	7,103	103,412	0.7%
HI	7,001	99,963	0.7%
OK	6,140	239,955	1.6%
UT	6,092	245,645	1.6%
TX	6,039	1,457,387	9.7%
BOTTOM 5 STATES			
NJ	5,399	394,237	2.6%
MO	5,352	305,264	2.0%
IN	5,338	239,258	1.6%
DE	5,275	28,492	0.2%
IA	5,226	143,398	0.9%

Figure 4-13 – Public Supply Energy Intensity (kBTU/MG)



4.2.3 Wastewater Treatment

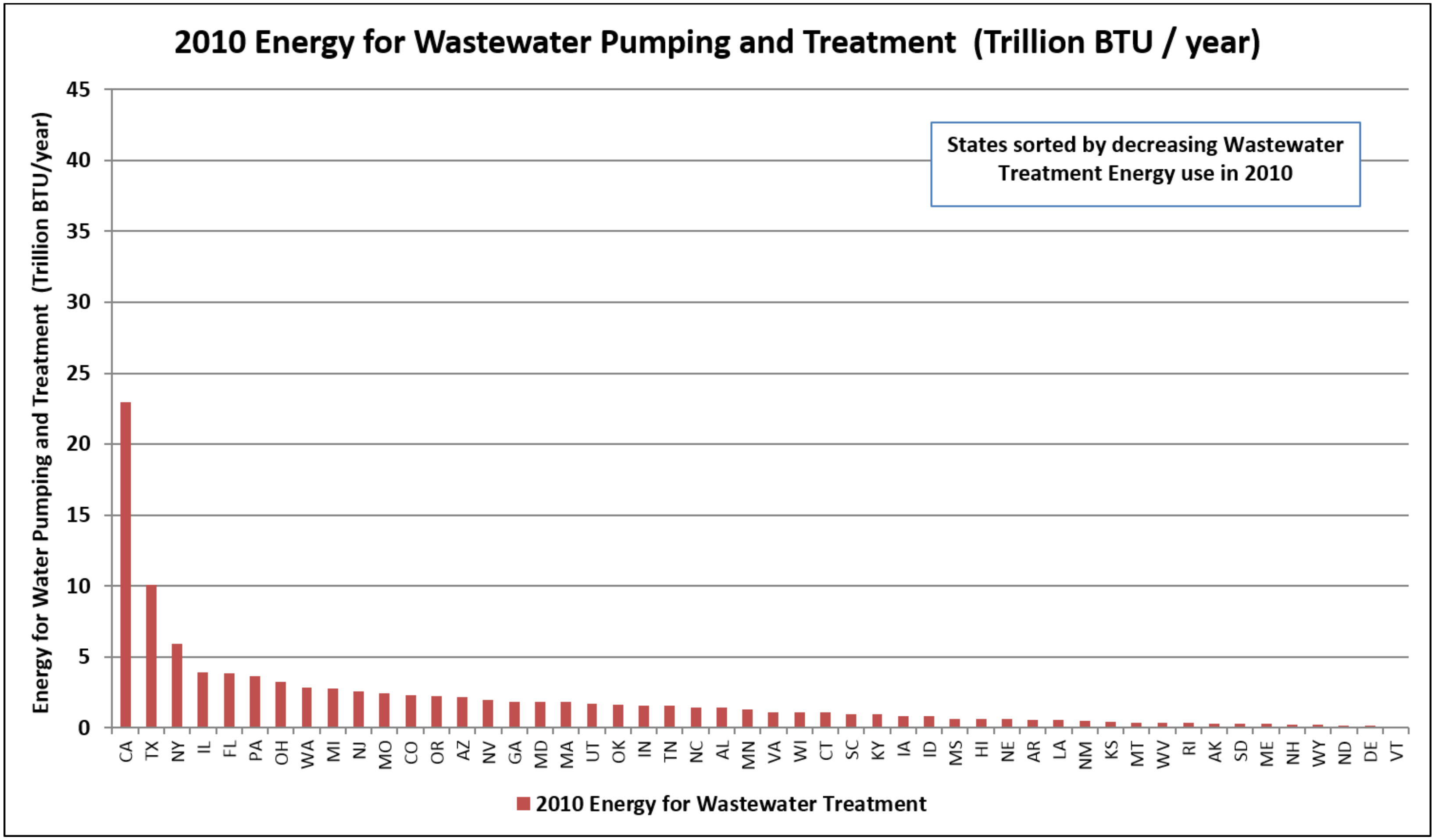
Energy Used for Wastewater Treatment

The top states using energy for wastewater treatment are the top 10 states with urban and suburban populations. The energy intensity of wastewater treatment (below) varies somewhat from state to state. However, the driving force behind energy use in this sector is the total quantity of wastewater treated, which tends to scale with population.

Table 4-14 – Top 10 States for 2010 Energy for Wastewater Treatment
The top 10 states total 60% of energy for wastewater treatment

Live Link Database Variables	= LLB_WWE	
Data Type	2010 Energy for Wastewater Treatment (TBTU)	2010 % Energy for Wastewater Treatment
State Totals	**102.7**	**100%**
TOP 10 STATES		
CA	22.9	22.3%
TX	10.1	9.8%
NY	5.9	5.7%
IL	3.9	3.8%
FL	3.9	3.8%
PA	3.6	3.6%
OH	3.3	3.2%
WA	2.9	2.8%
MI	2.8	2.7%
NJ	2.6	2.5%
BOTTOM 5 STATES		
NH	0.23	0.22%
WY	0.21	0.21%
ND	0.15	0.14%
DE	0.13	0.13%
VT	0.12	0.12%

Figure 4-14 – Energy for Wastewater Pumping and Treatment (Trillion BTU/year)



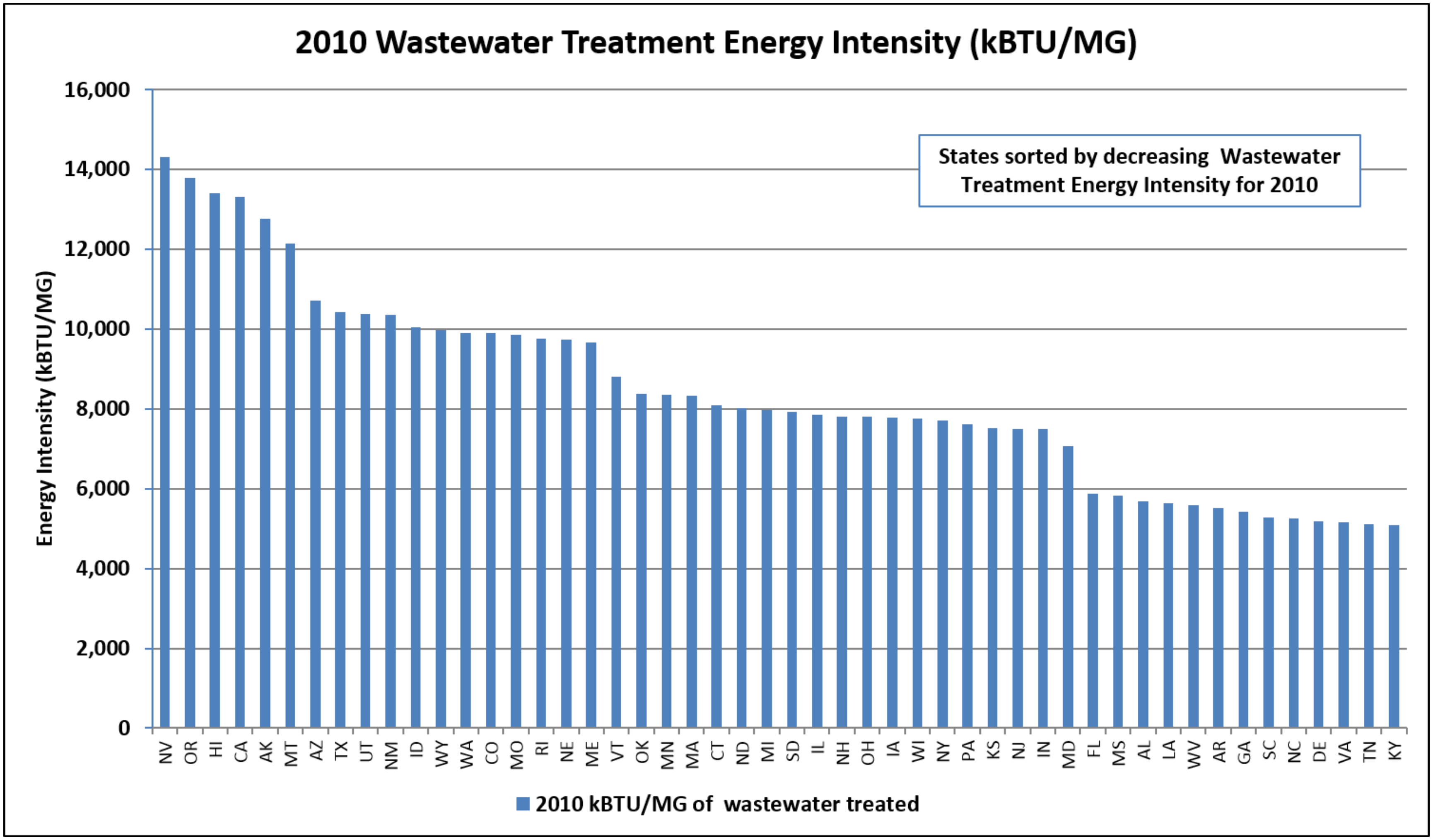
Energy Intensity of Wastewater Treatment

Variations in the energy intensity of wastewater treatment could not be accurately assessed in this analysis. Wastewater treatment intensity was estimated by applying regional statistics on wastewater treatment energy intensity to each state. These statistics were reported in units of primary energy (quantity of fuels used to produce the electricity that drives treatment and pumping processes). However, energy intensity here is reported in kBTU of electricity consumed in wastewater treatment operations, divided by the total quantity of treated water. Variations in a state's generation portfolio drive variations in the estimates for total electricity used. The top 10 states for energy intensity of wastewater treatment are all western states, as indicated by the region with the highest wastewater treatment energy intensity.

Table 4-15 – Top 10 States for 2010 Energy Intensity for Wastewater Treatment
The top 10 states total 30% of water treated

Energy Intensity	2010 Data Sorted by decreasing WW Energy Intensity		
Live Link Database Variables	= 1000000000*LLB_WWE / (365*LLB_WWW)	= 365*LLB_WWW	The top 10 states total 30% of water treated
Data Type	2010 kBTU/MG of wastewater treated	2010 MG of wastewater treated	2010 Percent of Total wastewater treated
	National Mass Avg.	Total WW treated	National & State %
	8,734	**11,760,270**	**100%**
TOP 10 STATES			
NV	14,309	135,763	1.15%
OR	13,799	162,814	1.38%
HI	13,417	47,737	0.41%
CA	13,319	1,721,406	14.64%
AK	12,756	25,457	0.22%
MT	12,147	28,371	0.24%
AZ	10,705	205,703	1.75%
TX	10,433	966,936	8.22%
UT	10,378	164,241	1.40%
NM	10,357	45,406	0.39%
BOTTOM 5 STATES			
NC	5264	272620	2.32%
DE	5183	25473	0.22%
VA	5150	216989	1.85%
TN	5119	302132	2.57%
KY	5098	192204	1.63%

Figure 4-15 – Wastewater Treatment Energy Intensity (kBTU/MG)



5 Conclusions

5.1 Summary

With these Sankey diagrams, state-level energy and water policymakers now have an additional information resource that informs discussions and decision-making. The diagrams, and the synthetic data upon which they are built, represents a new analysis of region-specific energy and water use data.

The report that accompanies these diagrams can serve as a primer for stakeholders across the energy-water nexus. The appendices to this report contain important information about the extent, as well as the limitations of the analysis that was performed.

Creating a Sankey diagram demands analytical rigor in both energy and water accounting. The flows on the diagram represent physical quantities that obey conservation laws. Such rigor is not possible when collecting energy and water use statistics in isolation. Energy and water can be "unaccounted for" or accounted differently by various data sources. These statistical limitations drive the diagram authors to make many assumptions, and not all of those assumptions can be conveyed through the diagram alone.

Importantly, the documentation of the assumptions that were made (mostly in appendix A) are instructive on the availability and limitations of state-level energy and water data. Furthermore, extensive stakeholder engagement and review of this report, the data and diagrams have illuminated alternate methodologies and assumptions that could be applied in future analyses.

The review process has indicated that there is a strong appetite for visual data products that inform policymakers of the nature and magnitude of interactions between energy and water resources and infrastructure

5.2 Future Work

Stakeholders who were interviewed during the course of this analysis have also made several suggestions for future work, including updates to the data, analysis, publication platform and ongoing community engagement.

5.2.1 Data Updates

Several opportunities to update the analysis will be possible as new data are released:

- Updated State- and County-level water withdrawal data, and some consumptive use data for the municipal, industrial, power generation and agricultural sectors are expected to be available from the USGS in 2019. These data should reflect the 2015 data-year.
- State-level energy use data for the 2015 data-year is available through EIA's SEDS data portal as of June 30, 2017.
- As discussed in Appendix A.1.3 and A.5.7, EIA made significant improvements to its data collection and analysis of withdrawal and consumption of water at thermoelectric power plants. Updating these charts to the 2015 data-year will take full advantage of these improvements and more confidently integrate the EIA water use estimates with USGS estimates.

Overall, the long delay between the most recent data (2010), the publication date of this report (2017) and the expected timing of the next set of releases (2019) indicates that there are opportunities to improve the frequency and timeliness of publishing energy and water statistical data. It is incumbent upon the entire community, and not just the statistical agencies, to advocate for and work towards more frequent, faster and better data. Improvements will entail more reliable collection, faster processing, better provenance (documentation of the source, analysis and confidence levels of published data sets) and more flexible access.

5.2.2 Analysis Updates

Further opportunities to improve the extent and detail of the analysis are also imminent:

- **Water use in Oil and Gas Extraction**: The Groundwater Protection Council (GWPC)'s FracFocus data collection effort continues to improve. Data on water use and production in unconventional oil and gas extraction are increasing in coverage, accuracy and availability. Specifically, it will be possible to work with GWPC and experts in the O&G industry to develop a more comprehensive analysis of water withdrawal and production, as well as water-remaining-in-formation (a form of consumption), water recycling, beneficial reuse and disposal via injection. Simply having this data is not enough to update the Sankey Diagrams. It will be possible to work with GWPC, state energy and water officials, federal agencies and industrial stakeholders to develop a model for visualizing water flow in unconventional O&G operations. Further research is needed on whether it is appropriate to add that level of detail to the existing Sankey Diagrams, or whether a separate analysis would be more appropriate.
- **Water Flows and Energy Use in Wastewater Treatment:** The EPA's Clean Watersheds Needs Survey (CWNS) contains data on the total flow of water into wastewater treatment systems. This data includes estimates of water discharged from industrial and residential and commercial customers, infiltration into collection systems and storm-water flows to wastewater treatment plants. It also contains data related to ocean discharge of treated wastewater. While the CWNS does not directly provide estimates of energy use by wastewater treatment plants, comparing the CWNS estimates of flows through wastewater treatment systems to flows estimated from residential and commercial consumption may substantially change the estimate of total energy used to treat wastewater. Although visualizing the flow of storm-water and collection-system infiltration on the Sankey diagram may initially cause some confusion, it is an opportunity to highlight the energy implications of wastewater collection technologies.
- **Wastewater Recycling:** Data collected by EPA as well as industry associations such as AWWA and WE&RF are likely to show significant increases in the adoption of municipal water recycling over the past decade. Three categories of water recycling could be depicted:
  - Beneficial reuse, where tertiary-treated municipal wastewater is used in industrial or irrigation applications
  - Indirect potable reuse, where highly treated and disinfected wastewater is used to recharge fresh groundwater aquifers
  - Direct potable reuse, where highly treated and disinfected wastewater is blended into the intake of water treatment plants.

  All three of these categories of reuse are small compared to withdrawals for municipal use, though reuse in water-stressed states is approaching 10%. Further research is required to optimize the visualization of recycling loops on the Sankey diagram, and to depict the tradeoff between additional energy required for recycling and the reduction of energy required for withdrawal and treatment of fresh water displaced by recycling.

- **Consumptive Use of Water:** In addition to improving the estimates of consumptive use of water in thermoelectric generation and oil & gas extraction (see above), it is incumbent upon the community of energy-water experts to update and improve estimates of consumptive use of water in the residential, commercial, industrial and agricultural sectors. Consumptive use analysis has been performed for individual facilities, industry sectors, certain states and regions, but coverage is far from complete. Multiple federal agencies are aware of the demand for these estimates.
- **Energy Efficiency:** State-level estimates for the energy efficiencies of the end use sector are not currently available. Because end-uses within sectors are varied, sectoral end-use efficiency is estimated as a combination of thermodynamic ("second law" or "exergy") efficiency, thermal ("first law") efficiency, utilization efficiency and benchmark efficiency (comparison to best available technology). Further research is required to determine whether enough data are available on a state-by-state basis to evaluate the efficiencies of the end use sectors on a consistent basis.
- **Fuel Refining:** The diagrams do not currently depict water and energy use in fuel and biofuel refining. Data related to water use in these energy conversions are readily available on a state-by-state basis. Further research is required to determine the best way to accommodate fuel and biofuel refining into the geometric constraints of the Sankey diagrams.
- **Imports and Exports:** Future versions of the Sankey diagrams could depict interstate imports and exports of water, petroleum, gas, coal and biofuels, much in the same way the current diagrams depict imports and exports of electricity. Some data on interstate water transfers are readily available for Western states. Further research is required to understand the best way to depict interstate water infrastructure in the Eastern states without adding the complexity of visualizing all of the natural flows through waterways that cross state lines.

5.2.3 Publication and Access

Improving the accessibility of these diagrams is also a high priority. Beyond distribution in this report, the diagrams will be made accessible as standalone, scalable and printable .pdf documents. Future work could enable more interactivity with the diagrams. For example, digital distribution in an interactive web framework could allow users of the diagrams to quickly obtain quantitative information on flows whose value are not explicitly communicated on the diagram, or to learn more about the assumptions that went into the flow's value without referring to this report or the associated data.

5.2.4 Research Community Coordination

Finally, work is already underway to coordinate the analysis performed in the construction of these diagrams with the broader energy-water data community. Researchers from across the country are investigating ways to combine and validate multiple layers:

- statistical energy and water use data (the inputs and outputs of this report)
- observed environmental data (precipitation, evaporation, river flows)
- modeled environmental data (climate and weather forecasts)
- infrastructure data
- modeled energy data (estimates of future energy flows)

Future work will involve formal collaboration and informal coordination with this community of data stakeholders.

6 References

ANL 2004. J.A. Veil, M. G. Puder, D. Elcock, R.J. Redweik, Jr. “A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane.” Prepared by: Argonne National Laboratory. Prepared for: U.S. Department of Energy, National Energy Technology Laboratory. www.ipd.anl.gov/anlpubs/2004/02/49109.pdf

AWWA. 2011. *Performance Indicators for Water and Wastewater Utilities: Survey Data and Analysis Report.* American Water Works Association. Data from Appendix C. http://www.awwa.org/

California. 2015. "Governor Brown Directs First Ever Statewide Mandatory Water Reductions." State of California Drought Information Website. 2015. http://drought.ca.gov/topstory/top-story-29.html

DOE. 2015a. *Quadrennial Energy Review, First Installment.* U.S. Department of Energy. 2015. http://energy.gov/epsa/quadrennial-energy-review-first-installment

DOE. 2015b. *Quadrennial Technology Review 2015.* U.S. Department of Energy. 2015. http://energy.gov/quadrennial-technology-review-2015

DOE. 2015c. "Energy Positive Wastewater Resource Recovery Workshop Report." U.S Department of Energy. 2015. http://www.energy.gov/sites/prod/files/2015/10/f27/epwrr_workshop_report.pdf

DOE. 2014. *The Water-Energy Nexus: Challenges and Opportunities.* U.S. Department of Energy. June 2014. http://energy.gov/sites/prod/files/2014/06/f16/Water%20Energy%20Nexus%20Report%20June%202014.pdf

DOE -EIA. 2016. “Crude Oil Production.” http://www.eia.gov/dnav/pet/PET_CRD_CRPDN_ADC_MBBLPD_A.htm

DOE-EIA. 2016. “Drilling Productivity Report.” http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_a.htm

DOE-EIA. 2015. EIA-860

DOE-EIA. 2015. “Natural Gas Gross Withdrawals and Production.” http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_a.htm

DOE-EIA. 2014. EIA Power plant environmental data. 2014. Water cooling by generator and boiler. https://www.eia.gov/electricity/data/water/

DOE-EIA. 2014. "SEDS Production Estimates Technical Notes For 1960-2012." U.S. Department of Energy, Energy Information Administration. Accessed 2014. http://www.eia.gov/state/seds/sep_prod/Prod_technotes.pdf

DOE-EIA. 2013a. “Form EIA-860 detailed data – 2011, Early Release." U.S. Department of Energy, Energy Information Administration. Accessed 2014. www.eia.gov/electricity/data/eia860/

DOE-EIA. 2013b. “Form EIA-923 detailed data. 2011." U.S. Department of Energy, Energy Information Administration. Accessed 2013. www.eia.gov/electricity/data/eia923/

DOE-EIA. 2013c. “The U.S. relies on foreign uranium, enrichment services to fuel its nuclear power plants” U.S. Department of Energy, Energy Information Administration. Today in Energy, August 3, 2013. http://www.eia.gov/todayinenergy/detail.cfm?id=12731

DOE-EIA. 2012. EIA-923

DOE-EIA. 2012. "Annual Energy Review." U.S. Department of Energy, Energy Information Administration. Accessed 2014. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf

DOE-EIA. 2011. EIA-923

DOE-EIA. 2010. EIA-923

EPRI. 2013. *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Electric Power Research Institute. Published 2013. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001433

eSankey. 2015. "e!Sankey Pro Version 4.0." ifu-Hamburg GmhH. Accessed 2015. http://www.e-sankey.com/en/download/

FracFocus. “Hydraulic Fracturing Water Usage.” http://fracfocus.org/water-protection/hydraulic-fracturing-usage.

FRIS. 2007. "Farm and Ranch Irrigation Survey of 2008." U.S. Department of Agriculture, documenting the USDA Census of Agriculture for 2007. Issued 2009. Accessed 2014. http://www.agcensus.usda.gov/Publications/2007/

FRIS. 2012. "Farm and Ranch Irrigation Survey of 2013." U.S. Department of Agriculture, documenting the USDA Census of Agriculture for 2012. Issued 2014. Accessed 2014. http://www.agcensus.usda.gov/Publications/2012/

LLNL. 2010a. “US Transportation Sankey Diagram and Report” Lawrence Livermore National Laboratory. LLNL-TR-513773. 2010. https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2005/2005USTransFullFV.pdf

LLNL. 2010b. “US Residential Sankey Diagram and Report” Lawrence Livermore National Laboratory. LLNL-TR-520271. 2010. https://e-reports-ext.llnl.gov/pdf/550009.pdf

LLNL. 2013. "U.S. Energy Flowchart 2013." Lawrence Livermore National Laboratory. LLNL-MI-410527 https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2013/2013USEnergy.png

Meldrum et al. 2013. Meldrum, J., Nettles-Anderson, S., Heath, G., Macknick, J.; *Life Cycle Water Use for Electricity Generation: A review and Harmonization of Literature Estimates*. Environmental Research Letter 8 015031. March, 2013. http://dx.doi.org/10.1088/1748-9326/8/1/015031

Microsoft. 2014. "Microsoft SQL Server 2012 SP1 PowerPivot for Microsoft Excel 2010." Microsoft Corporation. Accessed 2014. http://www.microsoft.com/en-us/download/details.aspx?id=29074

Mielke, E., Diaz, L. and Marayanamurti, V. 2010. *Water Consumption of Energy Resource Extraction, Processing, and Conversion*. Energy Technology Innovation Policy Discussion Paper Series. Discussion Paper #2010-15. October 2010; http://belfercenter.ksg.harvard.edu/files/ETIP-DP-2010-15-final-4.pdf

NASS. 2014. "USDA National Agricultural Statistics Service" U.S. Department of Agriculture. Accessed 2015. http://quickstats.nass.usda.gov/

NETL. 2015. Shuster, E. P., Expert Analysis and Estimates. Private communication.

Scanlon, Reedy and Nicot. 2014. *Comparison of Water Use for Hydraulic Fracturing for Unconventional Oil and Gas versus Conventional Oil*; Environ. Sci. Technol., 2014, 48 (20), pp 12386–12393. September, 2014. http://pubs.acs.org/doi/pdf/10.1021/es502506v

SEDS. 2010. "State Energy Data System." U.S. Department of Energy, Energy Information Administration. Accessed 2014. http://www.eia.gov/state/seds/

Tidwell, V., Moreland, B. and Zemlick, K. 2014. *Geographic Footprint of Electricity Use for Water Services in the Western U.S.* Environmental Science and Technology, August, 2014;48(15):8897-8904. http://pubs.acs.org/doi/pdf/10.1021/es5016845

USGS. 1995. "Circular 1200; Estimated Use of Water in the United States in 1995." United States Geological Survey. Published 1998. http://pubs.er.usgs.gov/publication/cir1200

USGS. 2005. "Circular 1344; Estimated Use of Water in the United States in 2005." United States Geological Survey. Published 2009. http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf

USGS. 2005. "Circular 1405; Estimated Use of Water in the United States in 2010." United States Geological Survey. Published 2014. http://pubs.usgs.gov/circ/1405/

University of Texas at Austin. “Water Use for Fracking Oil Resembles Use for Conventional Production.” UT News press release, September 29, 2014. http://news.utexas.edu/2014/09/29/water-use-fracking.

Veil. 2015. Veil Environmental, LLC 2015. J. Veil. “U.S. Produced Water Volumes and Management Practices in 2012.” Prepared for: the Ground Water Protection Council. http://www.gwpc.org/sites/default/files/Produced%20Water%20Report%202014-GWPC_0.pdf

Wu et al. 2011. M. Wu, M. Mintz, M. Wang, S. Arora, Y. Chiu. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline – 2011 Update*. Argonne National Laboratory (ANL). 2011 https://greet.es.anl.gov/publication-consumptive-water

Appendix A – Calculations: Data, Analysis and Assumptions

A.1 Energy Resources

A.1.1 Petroleum

Petroleum Production: Petroleum production is defined as the amount of crude oil extracted from wells within a state. Petroleum production is reported directly in SEDS under the data-code PAPRB. No assumptions or calculations are used to infer state-level petroleum production.

Petroleum Use: Petroleum energy use in each state is reported directly in SEDS under the data-code PMTCB. No assumptions or calculations are used to infer state-level petroleum consumption; the PMTCB data point is used directly.

PMTCB includes the petroleum products (gasoline, diesel fuel, kerosene, naptha and other oils) used in the electricity, residential, commercial, industrial, and transportation sectors. As a cross check, it is confirmed that PMTCB is equal to the sum of petroleum use in each of these sectors on a state-by state basis. PMTCB does NOT include the biomass-derived oxygenates (primarily ethanol) that are blended into fuels (primarily gasoline).

The components of petroleum use on a sector-by sector basis are described in the following sections:

A.3.1 Petroleum Use in Electricity Generation

A.4.1 Petroleum Use in the Transportation Sector

A.4.2 Petroleum Use in the Residential Sector

A.4.3 Petroleum Use in the Commercial Sector

A.4.4 Petroleum Use in the Industrial Sector

Petroleum Water Withdrawal: Water is used in the extraction of petroleum. The largest uses of withdrawn water are for primary recovery, secondary flooding, enhanced oil recovery and hydraulic fracturing. In this analysis, all water used for petroleum production is assumed to be fresh surface or groundwater. Saline surface and groundwater withdrawals are not calculated. Because the balance of petroleum production is shifting due to rapidly evolving hydraulic fracturing technology, water withdrawn from shale and tight formations (primarily hydraulically fractured) petroleum operations is calculated separately from other (so-called "conventional") petroleum operations, and these two terms are added together. The total water withdrawals for oil production are shown on the Sankey diagram.

Fresh Surface Water: NETL developed independent estimates of fresh surface water used for shale and tight oil production (UO_WSWFr) for the top 12 oil producing states that have significant unconventional production (Arkansas, California, Colorado, Kansas, Louisiana, Montana, New Mexico, North Dakota, Oklahoma, Texas, Utah, Wyoming). These estimates were used directly, and are reported in Appendix B.5.1.

For conventional wells, the total quantity of conventional oil produced ($P_{oil,conv}$) was calculated from the difference between SEDS record of total state-level crude oil production (recorded using the SEDS data-code PAPRP) and NETL's estimate of the unconventional oil extracted from the top 7 oil producing shale plays. The volume of conventional oil was multiplied by a water-use-to-oil production factor (WU_OP_{conv}) to find the total freshwater withdrawn for conventional oil production. The water-to-oil production factor varies by PADD region from 0.1 to 5.4 gallons-water to gallons-oil-produced (See Appendix B.5.1 reproduced from Wu, 2011). NETL assumes 80% of water withdrawn for conventional oil production to be fresh surface water. Therefore, the total quantity of fresh surface water withdrawn for oil production is:

$$P\_WSWFr = UO\_WSWFr + 0.8 * WU\_OP_{conv} * P_{oil,conv}$$

Fresh Groundwater: NETL developed independent estimates of fresh groundwater used for shale and tight oil production (UO_WGWFr) for the top 12 oil producing states that have significant unconventional production. These estimates were used directly, and are reported in Appendix B.5.1..

For conventional wells, the total quantity of conventional oil produced ($P_{oil,conv}$) was calculated as above. The volume of conventional oil was multiplied by a PADD-dependent water-use-to-oil production factor (Appendix B.5.2) gallons-water/gallon-oil to find the total freshwater withdrawn for conventional oil production. NETL assumes 18% of water withdrawn for conventional oil production to be fresh surface water. Therefore, the total quantity of fresh surface water withdrawn for oil production is:

$$P\_WGWFr = UO\_WGWFr + 0.18 * WU\_OP_{conv} * P_{oil,conv}$$

Recycled Water: Water that is recycled in the petroleum sector (produced water that is consumed in a later stage of production, or produced water that is sent to a different well) is not shown on the diagram. The 2% of water used for conventional oil production not accounted for by surface or groundwater is attributed to recycled water. Because this water is not a withdrawal, it is not included in the total shown on the diagram (see below).

Petroleum Water Production and Disposition:

The Sankey diagram depicts three modes of disposition of oil-associated produced water.

(1) discharges to surface water
(2) consumption and evaporation
(3) injection for permanent disposal

Two additional modes of produced water disposition are not depicted:

- re-injection for enhanced production at other oil and natural gas wells. Although some information on water recycling within the oil and natural gas sector is available, there is not enough information to quantify the relationship between recycled water and groundwater withdrawal. There is also not enough information to quantify exchanges of water between the oil and natural gas sectors. Finally, internal flows within a specific sector are not depicted on the diagram for the sake of simplicity.
- discharges to saline surface water. Information on ocean water operations (from, for example, offshore oil production activities) is not readily available.

Disposition of produced water associated with petroleum extraction was calculated from the analysis of the data compiled by Veil (Veil. 2015). This data is for the 2012 year, and we have not modified the data to extrapolate back to 2010 oil production levels.

Veil reports the total quantity of produced water that is managed in each state for 31 major oil and natural gas producing states. Veil also describes six modes of disposition for oil and natural gas produced water:

- Injection for Enhanced Recovery
- Injection for Disposal
- Offsite Commercial Disposal
- Surface Discharge
- Beneficial Reuse
- Evaporation

The Veil data, though more detailed than any other compilation of produced water data at the state level, does not assign portions of any of these water flows to oil or natural gas specifically. Additionally, data is not available for all disposition methods for all states. However, Veil does report the total quantity of oil ($OilProd_{Veil2012}$), and the total quantity of natural gas ($GasProd_{Veil2012}$) produced in each state.

For some states, Veil reports the total quantity of water produced from each of the oil and natural gas sectors. For these states, a Water-to-Oil Ratio (WOR) and a Water-to-Gas Ratio (WGR) is calculated. For states where WOR and WGR are not provided by Veil, they are initially estimated to be equal to the WOR and WGR of a neighboring oil and natural gas producing state. In some cases, the average WOR and WGR of two surrounding states was used to provide an initial estimate. A final WOR and WGR for these states are calculated by adjusting the more influential (WOR for states with greater oil production, and WGR for states with greater natural gas production) parameter until the sum of:

$$(WOR^* \, OilProd_{Veil2012}) + (WGR^* \, GasProd_{Veil2012})$$

matched the total quantity of produced water from the combined oil and natural gas sectors reported by Veil.

For a few other states, the WOR and WGR, as provided by Veil, resulted in a produced water total that did not equal Veil's own statistics on produced water managed. In these cases, both WOR and WGR were adjusted together. The table below shows the calculated WOR for all states in Veil's report, as well as the estimation method:

State	WOR	Estimation
AL	3.3	Provided by Veil
AK	4	Provided by Veil
AZ	1.3	Provided by Veil
AR	26.6	Provided by Veil
CA	15.5	Provided by Veil
CO	4.6	Average of NM, AZ WOR
FL	28.8	AR WOR of 26.6 adjusted upwards
IL	11.8	Provided by Veil
IN	20.8	Provided by Veil
KS	22.2	Provided by Veil
KY	6	Average of IL, OH WOR of 6.4, adjusted downwards
LA	10.904	MS WOR of 9.4 adjusted upwards with WGR
MI	3.4	Provided by Veil
MS	9.4	Provided by Veil
MO	12	Provided by Veil
MT	6.8	Provided by Veil
NE	23	Provided by Veil
NV	15.9	Provided by Veil
NM	7.9	Provided by Veil
NY	0.6	Total water managed is zero, so this is unused.
ND	1.2	Provided by Veil
OH	2.7	Multiplied both WOR and WGR by 2.7
OK	24.738	Multiplied both WOR and WGR by 0.93
PA	2.1	NY WOR of 0.6 adjusted upwards to 2.1

SD	3	Provided by Veil
TN	1.65	Multiplied both WOR and WGR by 0.5
TX	11.297	Multiplied both WOR and WGR by 1.43
UT	4.35	Average of AZ, NM WOR of 4.6, adjusted downwards
VA	5.6	Provided by Veil
WV	3.3	Average of OH, VA WOR
WY	19.602	Multiplied both WOR and WGR by 0.54

With WOR and WGR consistent with the total quantity of produced water managed, the fraction of oil-and- natural gas produced water allocated to oil is calculated as:

$$FWOil_{Veil2012} = (WOR^* \ OilProd_{Veil2012}) / ((WOR^* \ OilProd_{Veil2012}) + (WGR^* \ GasProd_{Veil2012}))$$

The flows of produced water to each of Veil's six disposition categories are then calculated by multiplying each of the reported oil-and- natural gas flows to that disposition by $FWOil_{Veil2012}$.

Injected: Veil's Injection data, as calculated for oil production, is added to Veil's Offsite Commercial Disposal data as calculated for oil production. This results in a total of the water that eventually is injected underground.

Surface Discharge: Veil's Surface Discharge data, as calculated for oil production, is added to Veil's Beneficial Reuse data, as calculated for oil production. This results in a total of the water that eventually flows back to surface water bodies.

Evaporation and Consumption: Veil's Evaporation data, as calculated for oil production, is used directly to represent the flow from petroleum production to Evaporation and Consumption.

A.1.2 Biomass

Biomass Production: Biomass production in a given state is assumed to be equal to the quantity of feedstock that is used to produce ethanol. Raw biofuels (wood and waste) are not included in this calculation of biomass production, because the goal of this analysis was to examine the relationship between energy production and water consumption. Water withdrawals are generally not a factor in wood and waste production. Feedstock for ethanol is reported directly in SEDS under the data-code EMFDB. No additional calculations are used to infer state-level biomass production.

Biomass Use: Biomass energy use is calculated as the sum of waste-to-energy inputs, wood fuel and ethanol consumed. Wood and waste are reported together under the SEDS data-code WWTCB. Ethanol consumption is reported under the SEDS data-code EMTCB. These two data points are added together to calculate total biomass use.

WWTCB includes wood used in the residential sector as well as the wood and waste used in the electricity, commercial, and industrial sectors. Wood and waste consumption in the transportation sector is negligible. EMTCB includes the ethanol portion of all liquid fuels consumed in the transportation, commercial and industrial sectors. Ethanol consumption in the electric and residential sectors is negligible. As a cross-check, it is confirmed that the sum of WWTCB and EMTCB are equal to the quantities of wood, waste and ethanol consumed by all sectors.

The components of biomass use on a sector-by sector basis are described in the following sections:

A.3.1 Biomass Use in Electricity Generation

A.4.1 Biomass Use in the Transportation Sector

A.4.2 Biomass Use in the Residential Sector

A.4.3 Biomass Use in the Commercial Sector

A.4.4 Biomass Use in the Industrial Sector

Biomass Water Withdrawal: Water is used for the irrigation of biomass crops. The dominant irrigated biomass crop is corn for ethanol production; irrigation of other crops for alternate biofuels (such as biodiesel) is an insignificant fraction of biomass water use. This analysis focuses on the irrigation of corn for ethanol production. Total withdrawals of water for biomass production are calculated as the sum of fresh surface water for biomass production and fresh groundwater for biomass production.

Calculation of the total water use for corn ethanol production is complicated by the fact that not all corn is used for ethanol production, and not all corn is irrigated. Three important factors were considered when calculating water used for biomass production:

- The fraction of corn used in each state for ethanol production (FC_{eth}). This fraction is calculated by dividing the required bushels of corn for ethanol production within a state (calculated from the total production of ethanol recorded in SEDS under the data code ENPRP and the corn required per unit of ethanol ($CI_{eth,bushels}$)) by the total bushels of corn produced ($CProd_{bushels}$)within that state (reported in USDA's NASS database).

$$FC_{eth} = \frac{ENPRP * CI_{eth,bushels}}{CProd_{bushels}}$$

- The total number of *irrigated* acres of corn harvested within a state ($AC_{corn,irr}$). USDA's Farm and Ranch Irrigation Survey (FRIS) reports the number of irrigated acres of corn in each state.
- The irrigation intensity (in MGD per acre) for the portion of corn that is irrigated (II_{corn}). FRIS also reports irrigation intensity of irrigated acres on a state-by-state basis.

To calculate the water used for corn-ethanol, the total amount of water used for corn irrigation is multiplied by the fraction of corn that is consumed in producing ethanol. We rely on the assumption that irrigated and non-irrigated corn is used in ethanol production in proportion to their production within a state. The total amount of water withdrawn for the production of biomass (W_{bio}) is the product of the above terms

$$W_{bio} = FC_{eth} * \left(AC_{corn,irr} * II_{corn}\right)$$

Fresh Surface Water: FRIS reports the number of corn acres irrigated from groundwater, from surface water and from off-farm supplies (which are assumed to be surface-water). We assume that water withdrawals scale proportionally with the number of acres irrigated. The fraction of irrigation supplied from surface water is calculated from FRIS acreage data (and represented here as $SWFrac_{irr}$). FRIS also reports a fraction of irrigated acreage using "off farm" water (represented here as a fraction: $OFFrac_{irr}$), and the off-farm fraction of irrigation water is assumed to come from surface water supplies. Surface water used for biomass production (BIO_WSWFr) is then the product of W_{bio} and the sum of $OFFrac_{irr}$ and $SWFrac_{irr}$.

Fresh Groundwater: The fraction of irrigation supplied from groundwater is calculated from FRIS acreage data (as above) ($GWFrac_{irr}$). Groundwater used for biomass production (BIO_WGWFr) is then the product of W_{bio} and $GWFrac_{irr}$.

Disposition of Water used in Biomass Production: The water used in biomass production undergoes processes identical to water used in agricultural irrigation, described below in A.4.5. Water used to irrigate biomass is not discharged to public/municipal wastewater treatment facilities, discharged to the ocean or disposed via injection. Therefore, the only two modes of water disposition from biomass production are consumption and surface discharge.

Consumptive Use: There are no recent estimates of consumptive use of for irrigation on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, an "irrigation consumptive fraction" was calculated from the ratio of irrigation water consumption to total irrigation withdrawals in 1995. This fraction describes the consumptive use of water in the production of biomass ($CF_{ag,ir}$). The total consumptive use of water in the production of biomass is the product of the total water withdrawal and this consumptive fraction.

Surface Discharge: Surface discharge from biomass production (largely run-off from irrigated corn acreage) is calculated as the difference between total withdrawals in for biomass production (see above) and consumptive use (also above).

A.1.3 Natural Gas

Natural Gas Production: Natural gas production is defined as the amount of natural gas extracted from oil and natural gas wells within a state that is marketed for production. Flared natural gas is not included in this analysis. Marketed natural gas production is reported directly in SEDS under the data-code NGMPB. No assumptions or calculations are used to infer state-level natural gas production.

Natural Gas Use: Natural gas energy use in each state is reported directly in SEDS under the data-code NGTCB. No assumptions or calculations are used to infer state-level natural gas consumption; the NGTCB data point is used directly.

NGTCB includes the natural gas used in the electricity, residential, commercial, industrial, and transportation sectors. As a cross check, it is confirmed that NGTCB is equal to the sum of natural gas use in each of these sectors on a state-by state basis.

The components of natural gas use on a sector-by sector basis are described in the following sections:

A.3.1 Natural Gas Use in Electricity Generation

A.4.1 Natural Gas Use in the Transportation Sector

A.4.2 Natural Gas Use in the Residential Sector

A.4.3 Natural Gas Use in the Commercial Sector

A.4.4 Natural Gas Use in the Industrial Sector

Natural Gas Water Withdrawal: Water is used in the extraction of natural gas, primarily in hydraulic fracturing. In this analysis, all water used for natural gas production is assumed to be fresh surface or groundwater. Saline surface and groundwater withdrawals are not calculated. In this analysis, only the water used for hydraulically fractured (or "unconventional") natural gas is considered. Water use in the extraction of natural gas from conventional reservoirs is not considered. Water withdrawals for natural gas production are shown on the Sankey diagram.

Fresh Surface Water: NETL developed independent estimates of fresh surface water used for shale gas production (UG_WSWFr) for the top 15 natural gas producing states that have significant unconventional production (Arkansas, California, Colorado, Kansas, Louisiana, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, Utah, West Virginia, Wyoming). These estimates were used directly, and are reported in Appendix B.5.1..

Fresh Groundwater: NETL developed independent estimates of fresh groundwater used for shale gas production (UG_WGWFr) for the top 15 natural gas producing states that have significant unconventional production (see above). These estimates were used directly.

Recycled Water: Water that is recycled during the extraction of shale gas (produced water that is consumed in a later stage of production, or produced water that is sent to a different well) is not shown on the diagram (see below).

Natural Gas Water Production and Disposition:

The Sankey diagram depicts three modes of disposition of produced water associated with natural gas.

(4) discharges to surface water

(5) consumption and evaporation
(6) injection for permanent disposal

Two additional modes of produced water disposition are not depicted:

- re-injection for enhanced production at other oil and natural gas wells. Although some information on water recycling within the oil and natural gas sector is available, there is not enough information to quantify the relationship between recycled water and groundwater withdrawal. There is also not enough information to quantify exchanges of water between the oil and natural gas sectors. Finally, internal flows within a specific sector are not depicted on the diagram for the sake of simplicity.
- discharges to saline surface water. Information on ocean water operations (from, for example, offshore natural gas production activities) is not readily available.

Disposition of produced water associated with natural gas extraction was calculated from the analysis of the data compiled by Veil (Veil. 2015). This data is for the 2012 year, and we have not modified the data to extrapolate back to 2010 oil production levels.

Veil reports the total quantity of produced water that is managed in each state for 31 major oil and natural gas producing states. Veil also describes six modes of disposition for oil and natural gas produced water:

- Injection for Enhanced Recovery
- Injection for Disposal
- Offsite Commercial Disposal
- Surface Discharge
- Beneficial Reuse
- Evaporation

The Veil data, though more detailed than any other compilation of produced water data at the state level, does not assign portions of any of these water flows to oil or natural gas specifically. Additionally, data is not available for all disposition methods for all states. However, Veil does report the total quantity of oil ($OilProd_{Veil2012}$), and the total quantity of natural gas ($GasProd_{Veil2012}$) produced in each state.

For some states, Veil reports the total quantity of water produced from each of the oil and natural gas sectors. For these states, a Water-to-Oil Ratio (WOR) and a Water-to-Gas Ratio (WGR) is calculated. For states where WOR and WGR are not provided by Veil, they are initially estimated to be equal to the WOR and WGR of a neighboring oil and natural gas producing state. In some cases, the average WOR and WGR of two surrounding states was used to provide an initial estimate. A final WOR and WGR for these states is calculated by adjusting the more influential (WOR for states with greater oil production, and WGR for states with greater natural gas production) parameter until the sum of:

$$(WOR^* \ OilProd_{Veil2012}) + (WGR^* \ GasProd_{Veil2012})$$

matched the total quantity of produced water from the combined oil and natural gas sectors reported by Veil.

For a few other states, the WOR and WGR, as provided by Veil, resulted in a produced water total that did not equal Veil's own statistics on produced water managed. In these cases, both WOR and WGR were adjusted together. The table below shows the calculated WGR for all states in Veil's report, as well as the estimation method:

State	WGR	Estimation
AL	318	Provided by Veil
AK	0.3	Provided by Veil
AZ	122.4	Provided by Veil

AR	9	Provided by Veil
CA	18.5	Provided by Veil
CO	97	Average of NM, AZ WGR, adjusted downwards
FL	9	AR WGR
IL	0	Provided by Veil
IN	981.3	Provided by Veil
KS	301	Provided by Veil
KY	3.95	Average of IL, OH WGR
LA	8.352	MS WGR of 7.2 adjusted upwards with WGR
MI	707.7	Provided by Veil
MS	7.2	Provided by Veil
MO	0	Provided by Veil
MT	55.9	Provided by Veil
NE	640.8	Provided by Veil
NV	0	Provided by Veil
NM	80.7	Provided by Veil
NY	0	Total water managed is zero, so this is unused.
ND	25.9	Provided by Veil
OH	21.33	Multiplied both WOR and WGR by 2.7
OK	8.37	Multiplied both WOR and WGR by 0.93
PA	11.1	NY WGR
SD	0	Provided by Veil
TN	159	Multiplied both WOR and WGR by 0.5
TX	115.401	Multiplied both WOR and WGR by 1.43
UT	101.55	Average of AZ, NM WGR
VA	21.8	Provided by Veil
WV	10	Average of OH, VA WOR of 14.85, adjusted downward
WY	138.024	Multiplied both WOR and WGR by 0.54

With WOR and WGR consistent with the total quantity of produced water managed, the fraction of oil-and- natural gas produced water allocated to natural gas is calculated as:

$$FWGas_{Veil2012} = (WGR^* \, GasProd_{Veil2012}) / ((WOR^* \, OilProd_{Veil2012}) + (WGR^* \, GasProd_{Veil2012}))$$

The flows of produced water to each of Veil's six disposition categories is then calculated by multiplying each of the reported oil-and- natural gas flows to that disposition by $FWGas_{Veil2012}$.

Injected: Veil's Injection data, as calculated for natural gas production, is added to Veil's Offsite Commercial Disposal data as calculated for natural gas production. This results in a total of the water that eventually is injected underground.

Surface Discharge: Veil's Surface Discharge data, as calculated for natural gas production, is added to Veil's Beneficial Reuse data, as calculated for natural gas production. This results in a total of the water that eventually flows back to surface water bodies.

Evaporation and Consumption: Veil's Evaporation data, as calculated for natural gas production, is used directly to represent the flow from natural gas production to Evaporation and Consumption.

A.1.4 Coal

Coal Production: Coal production is defined as the amount of coal extracted from mines within a state. Coal production is reported directly in SEDS under the data-code CLPRB. No assumptions or calculations are used to infer state-level coal production.

Coal Use: Coal energy use in each state is reported directly in SEDS under the data-code CLTCB. No assumptions or calculations are used to infer state-level coal consumption; the CLTCB data point is used directly.

CLTCB includes the coal used in the electricity, commercial, and industrial sectors. Although SEDS maintains placeholders for coal consumption in the residential and transportation sectors, coal use in these sectors has been negligible for many years and is reported as zero across all states. As a cross check, it is confirmed that CLTCB is equal to the sum of coal use in the electric, commercial and industrial sectors on a state-by state basis.

The components of coal use on a sector-by sector basis are described in the following sections:

A.3.1 Coal Use in Electricity Generation

A.4.3 Coal Use in the Commercial Sector

A.4.4 Coal Use in the Industrial Sector

Coal Water Withdrawal: Water is used in coal mining primarily for dust control, and is also used for some other purposes such as cooling, washing, etc. The water intensity of coal production depends primarily on whether the coal is being extracted from surface or underground mines. NETL and EIA data were used to estimate the surface/underground mining contributions to each state's coal production. NETL estimates that surface mines withdraw 7 gallons per ton of coal and underground mines withdraw 29 gallons per ton. Total coal water use is calculated as the sum of water withdrawn for surface mining and underground mining.

Coal mines may withdraw water from surface or groundwater resources, which are often fresh, and may also be saline (primarily brackish). This analysis assumes that coal mining operations withdraw water from each of these resources in proportion to the fractions of each water resource used for a state's entire mining industry. For example, the amount of fresh surface water used in coal mining is equal to the total amount of water used in coal mining, multiplied by the total amount of fresh surface water used for all mining, and divided by the total amount of water (fresh, saline, surface and ground) used for all mining. Fresh, saline, surface and groundwater use in the mining industry are reported directly by USGS.

Disposition of Water Used in Coal Mining: Water used in coal mining may be consumed or discharged to surface water supplies. Disposal of coal-mining wastewater through subsurface injection is not included in this analysis. Because coal mining operations near the coastline are negligible, discharge to the ocean is also assumed to be zero.

Consumptive Use: There are no recent estimates of consumptive use of water in the coal sector on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, a pair of "coal mining consumptive fractions" was calculated from the ratio of mining water consumption to mining water use in 1995. These fractions describe the consumptive use of freshwater ($CF_{coal,fr}$) and saline water ($CF_{coal,sa}$) in the coal mining sector. The total consumptive use of water in the coal sector (CU_{coal}), as defined in this analysis, is calculated as the sum of the consumptive use of fresh water for coal extraction ($CU_{coal,fr}$) and the consumptive use of saline water for coal extraction ($CU_{coal,sa}$). Each of these terms is defined as follows:

Consumptive use of water for coal extraction is calculated from the quantities of fresh and saline surface and groundwater withdrawn for coal mining. These quantities are calculated by NETL as above and given the following names here: CL_WSWFr, CL_WSWSa, CL_WGWFr, CL_WGWSa:

$$CU_{ind,non-mining} = CF_{coal,fr} * (CL\_WSWFr + CL\_WGW) + CF_{coal,sa} * (CL\_WSWSa + CL\_WGWSa)$$

Discharge to Surface: Surface discharge by coal mining is calculated as the difference between the sum of water withdrawals in the sector, and the total consumption, computed above.

A.1.5 Nuclear

Nuclear Energy Use: Nuclear energy is used to generate electricity in nuclear power plants. In these plants, thermal energy from nuclear fission is converted to electricity. The thermal energy released from nuclear fission in these plants is reported directly in SEDS under the data-code NUEGB. No assumptions or calculations are used to infer state-level nuclear energy consumption; the NUEGB data point is used directly. The electricity generation sector is the only sector to use nuclear energy.

A.1.6 Geothermal

Geothermal Energy Use: Geothermal energy is a heating (or cooling) service provided by underground reservoirs through the extraction or circulation of heat transfer fluids (often water/steam). Geothermal energy use in each state is reported directly in SEDS under the data-code GETCB. No assumptions or calculations are used to infer state-level geothermal consumption; the GETCB data point is used directly.

GETCB includes the geothermal energy used in the electricity, residential, commercial, and industrial sectors. Geothermal energy is not used in the transportation sector. As a cross check, it is confirmed that GETCB is equal to the sum of geothermal use in the electric, residential commercial and industrial sectors on a state-by state basis.

The appropriateness and usefulness of geothermal energy depends largely on the relationship to the geothermal resource to its application, and these vary widely between the electric and other sectors. Components of geothermal use on a sector-by sector basis are described in detail in the following sections:

A.3.1 Geothermal Use in Electricity Generation

A.4.2 Geothermal Use in the Residential Sector

A.4.3 Geothermal Use in the Commercial Sector

A.4.4 Geothermal Use in the Industrial Sector

A.1.7 Hydro

Hydroelectric Energy Use: Energy can be extracted from hydraulic head (the potential of water at elevation to do work as it flows downwards) and, to a lesser extent, from hydrokinetic energy (the energy carried by flowing water). Hydroelectric energy use in each state is reported directly in SEDS under the data-code HYTCB. No assumptions or calculations are used to infer state-level hydro consumption; the HYTCB data point is used directly. SEDS computes HYTCB by converting the total amount of electricity generated at hydroelectric facilities to a quantity of thermal energy that would have to be supplied to a typical fossil-fueled power plant to generate an equivalent amount of electricity.

HYTCB includes the hydro energy used in the electricity, commercial, and industrial sectors. Hydroelectric energy is not used in the residential or transportation sectors. As a cross check, it is confirmed that HYTCB is equal to the sum of hydro use in the electric, commercial and industrial sectors on a state-by state basis.

Components of hydroelectric use on a sector-by sector basis are described in the following sections:

A.3.1 Hydro Use in Electricity Generation

A.4.3 Hydro Use in the Commercial Sector

A.4.4 Hydro Use in the Industrial Sector

A.1.8 Wind and Solar

Wind and Solar Energy Use: Kinetic energy can be extracted from the wind to produce electricity. Wind energy used to create electricity in each state is reported directly in SEDS under the data-code WYTCB. SEDS computes WYTCB by converting the total amount of electricity generated at wind energy facilities to a quantity of thermal energy that would have to be supplied to a typical fossil-fueled power plant to generate an equivalent amount of electricity. Wind energy is used to generate electricity primarily in the electricity generation sector, and to a much lesser extent in the commercial and industrial sectors. Wind energy is not used in the transportation sector

Radiative energy in sunlight can be converted directly to electricity in photovoltaic equipment, can be converted to thermal energy for space or process heating in low-temperature thermal applications, and can be converted to high-temperature thermal energy and subsequently converted to electricity in concentrating solar power applications. Solar energy used for both electric generation and heating applications is reported directly in SEDS under the data-code SOTCB. The portion of solar energy used to generate electricity is computed by converting the total amount of electricity generated at photovoltaic and concentrating solar facilities to a quantity of thermal energy that would have to be supplied to a typical fossil-fueled power plant to generate an equivalent amount of electricity. Solar energy is used in the electric, residential, commercial and industrial sectors. It is not used in the transportation sector.

In this analysis, the total of wind and solar energy use in each state are reported together as the sum of WYTCB and SOTCB. No further assumptions or calculations are used to infer solar and wind energy consumption.

Components of wind and solar use on a sector-by sector basis are described in detail in the following sections:

A.3.1 Wind and Solar Use in Electricity Generation

A.4.2 Distributed solar Use in the Residential Sector, including both solar thermal and photovoltaic

A.4.3 Wind and Solar Use in the Commercial Sector

A.4.4 Wind and Solar Use in the Industrial Sector

A.2 Water Resources

A.2.1: Fresh Surface

Fresh Surface Water Withdrawals: Fresh surface water is defined by the USGS as water from lakes, rivers or other bodies of water in contact with the air that contains less than 1000 mg per liter of dissolved solids. Fresh surface water is a major component of municipal water supply, and is also used for agriculture, cooling of power plants, and industrial purposes. The residential and commercial sectors rarely access fresh surface water directly.

Fresh surface water withdrawals are reported in USGS Circular 1405 under the data-code TO_WSWFr. No assumptions or calculations are used to infer state-level fresh surface water consumption; the TO_WSWFr data point is used directly.

Specific information about the use of fresh surface water in the production of energy resources is in the following sections:

A.1.1 Fresh Surface Water Use in the Production of Petroleum

A.1.2 Fresh Surface Water Use in the Production of Biomass

A.1.3 Fresh Surface Water Use in the Production of Natural Gas

A.1.4 Fresh Surface Water Use in the Production of Coal

Specific information about the use of fresh surface water outside the energy sector is found in the following sections:

A.3.1 Fresh Surface Water Use for Thermoelectric Cooling

A.3.2 Fresh Surface Water Use for Public Water Supply

A.4.4 Fresh Surface Water Use in the Industrial and Mining Sector

A.4.5 Fresh Surface Water Use for Agricultural Irrigation, Livestock and Aquaculture

A.2.2: Saline Surface

Saline Surface Water Withdrawals: Saline surface water is defined by the USGS as water, in contact with the air, that contains more than 1000 mg per liter of dissolved solids. The vast majority of saline surface water withdrawals are taken from the ocean - much smaller quantities are found in salt-laden ponds or lakes. Saline surface water provides cooling for thermoelectric and industrial processes (primarily at the coast). Saline water is not directly suitable for irrigation, but some small quantities are used in aquaculture. Withdrawal and subsequent desalination for municipal, industrial and other uses is an active area of research and growth.

Saline surface water withdrawals are reported in USGS Circular 1405 under the data-code TO_WSWSa. No assumptions or calculations are used to infer state-level saline surface water consumption; the TO_WSWSa data point is used directly.

Specific information about the use of saline surface water in the production of energy resources is in the following sections:

A.1.1 Saline Surface Water Use in the Production of Petroleum

A.1.3 Saline Surface Water Use in the Production of Natural Gas

Specific information about the use of saline surface water outside the energy sector is found in the following sections:

A.3.1 Saline Surface Water Use for Thermoelectric Cooling

A.3.2 Saline Surface Water Use for Public Water Supply (desalination)

A.4.4 Saline Surface Water Use in the Industrial and Mining Sector

A.4.5 Saline Surface Water Use for Agricultural Irrigation, Livestock and Aquaculture

A.2.3: Fresh Ground

Fresh Groundwater Withdrawals: Fresh groundwater is defined by the USGS as water in underground aquifers that contains less than 1000 mg per liter of dissolved solids. Fresh groundwater is a major component of municipal water supply, and is also accessed directly by residences with their own groundwater wells. Fresh groundwater is used extensively in agriculture and industrial applications. Where it is abundant, fresh groundwater is also used for thermoelectric cooling. It is likely that fresh groundwater is used directly (apart from municipal supplies) in the commercial sector as well, although recent data is not available in that application.

Fresh groundwater withdrawals are reported in USGS Circular 1405 under the data-code TO_WGWFr. No assumptions or calculations are used to infer state-level fresh groundwater consumption; the TO_WGWFr data point is used directly.

Specific information about the use of fresh groundwater in the production of energy resources is in the following sections:

A.1.1 Fresh Groundwater Use in the Production of Petroleum

A.1.2 Fresh Groundwater Use in the Production of Biomass

A.1.3 Fresh Groundwater Use in the Production of Natural Gas

A.1.4 Fresh Groundwater Use in the Production of Coal

Specific information about the use of fresh groundwater outside the energy sector is found in the following sections:

A.3.1 Fresh Groundwater Use for Thermoelectric Cooling

A.3.2 Fresh Groundwater Use for Public Water Supply

A.4.2 Fresh Groundwater Use in the Residential Sector

A.4.4 Fresh Groundwater Use in the Industrial and Mining Sector

A.4.5 Fresh Groundwater Use for Agricultural Irrigation, Livestock and Aquaculture

A.2.4: Saline Ground

Saline Groundwater Withdrawals: Saline groundwater is defined by the USGS as water in underground aquifers that contains more than 1000 mg per liter of dissolved solids. Use of saline groundwater is limited to applications where freshwater resources are unavailable, and treatment and disposal costs are offset by the value of water use. Such applications include some inland thermoelectric cooling, mining and industrial applications. In some inland arid areas, low-salinity groundwater is treated to potable quality.

Saline groundwater withdrawals are reported in USGS Circular 1405 under the data-code TO_WGWSa. No assumptions or calculations are used to infer state-level saline groundwater consumption; the TO_WGWSa data point is used directly.

Specific information about the use of saline groundwater in the production of energy resources is in the following sections:

A.1.1 Saline Groundwater Use in the Production of Petroleum

A.1.3 Saline Groundwater Use in the Production of Natural Gas

A.1.4 Saline Groundwater Use in the Production of Coal

Specific information about the use of saline groundwater outside the energy sector is found in the following sections:

A.3.1 Saline Groundwater Use for Thermoelectric Cooling

A.3.2 Saline Groundwater Use for Public Water Supply (desalination)

A.4.4 Saline Groundwater Use in the Industrial and Mining Sector

A.3 Transformation, Distribution and Collection

A.3.1 Electricity

Electricity: Electricity is an energy commodity produced at power plants and used in almost every application in the residential, commercial and industrial sectors. Electricity is also used for pumping water in the agricultural sector, as well as for water and wastewater treatment. Electricity use in the transportation sector is small, but growing. Every energy resource (Solar, Wind, Geothermal, Hydro, Nuclear, Biomass, Coal, Natural Gas and Petroleum) is used to produce electricity. The production of electricity from energy resources is, on average, 35% efficient. The remaining 65% of energy in the conversion process is usually rejected to the environment as waste heat, and water is often used as a coolant. The electricity sector, therefore, is responsible for a significant amount of water withdrawal.

Energy consumption by the electricity generating sector is reported in SEDS under that data-code TEEIB. This statistic includes only electricity generated by dedicated electric and combined heat and power (CHP) utilities, and does not include electricity generated by industrially- or commercially-owned generation facilities that primarily serve their own load. TEEIB includes the flow of electricity into each state from imports into the US. Therefore, the total of energy resources consumed only for generation with in a state is TEEIB minus net imported electricity flow, which SEDS reports under the data-code ELNIB. The number reported for in-state generation is therefore TEEIB - ELNIB. No additional calculations are used to infer in-state generation. As a cross-check, it has been confirmed that this difference TEEIB - ELNIB is equivalent to the sum of all energy resources (see below) used to generate electricity.

Energy Resources Used to Produce Electricity:

Petroleum: Petroleum use in the electricity sector is recorded by SEDS under the data-code PAEIB. No assumptions or calculations are used to infer state-level petroleum use in the electricity sector beyond this value.

Biomass: Biomass use in the electricity sector is recorded by SEDS under the data-code WWEIB. These data include both wood and the bio-derived fraction of waste that are used in biomass-only, biomass-co-fired and waste-fueled generation facilities. No assumptions or calculations are used to infer state-level biomass use in the electricity sector beyond this value.

Natural Gas: Natural Gas use in the electricity sector is recorded by SEDS under the data-code NGEIB. No assumptions or calculations are used to infer state-level natural gas use in the electricity sector beyond this value.

Coal: Coal use in the electricity sector is recorded by SEDS under the data-code CLEIB. No assumptions or calculations are used to infer state-level coal use in the electricity sector beyond this value.

Nuclear: Consumption of nuclear energy in the electricity sector is recorded by SEDS under the data-code NUEGB. NUEGB represents the thermal output of nuclear powered steam generators, and does not directly correlate to the energy value of nuclear fuel. No assumptions or calculations are used to infer state-level nuclear energy use in the electricity sector beyond this value.

Geothermal: Geothermal energy inputs into the electricity sector are recorded by SEDS under the data-code GEEGB. No assumptions or calculations are used to infer state-level geothermal use in the electricity sector beyond this value.

Hydroelectricity: Energy inputs to utility-owned hydroelectric facilities are recorded by SEDS under the data-code HYEGB. SEDS computes HYEGB by converting the total amount of electricity generated at hydroelectric facilities to a quantity of thermal energy that would have to be supplied to a typical fossil-fueled power plant to generate an equivalent amount of electricity. No assumptions or calculations are used to infer state-level hydro use in the electricity sector beyond this value.

Wind and Solar: Energy inputs to utility-owned solar photovoltaic and solar thermal facilities are recorded by SEDS under the data-code SOEGB. Energy inputs to utility-owned wind-energy facilities are recorded by SEDS under the data-code WYEGB. SEDS computes both SOEGB and WYEGB by converting the total amount of electricity generated at solar and wind facilities to a quantity of thermal energy that would have to be supplied to a typical fossil-fueled power plant to generate an equivalent amount of electricity. The value of the flow from Wind and Solar to Electricity Generation is the sum of SOEGB and WYEGB. No additional assumptions or calculations are used.

Electricity Use Imports, Exports and Generation:

Electricity Use: The total amount of electricity consumed within a state is recorded by SEDS under the data code ESTCB. ESTCB includes the electricity consumed by the transportation, residential, commercial, industrial, agriculture, water treatment and wastewater treatment sectors. Detail on each of these sectors' consumption of electricity can be found in the following sections:

A.3.2 Electricity consumption in public and municipal water treatment

A.3.3 Electricity consumption wastewater treatment

A.4.1 Electricity consumption in the transportation sector

A.4.2 Electricity consumption in the residential sector

A.4.3 Electricity consumption in the commercial sector

A.4.4 Electricity consumption in the industrial sector

A.4.5 Electricity consumption in the agricultural sector

Electricity Imports: The total amount of energy consumed in out-of-state electricity generation facilities for electricity that is imported across state lines is reported in SEDS under the data-code ELISB. Similarly, the total amount of energy consumed in non-US electricity generation facilities for electricity that is imported from Canada and Mexico is reported in SEDS under the data-code ELNIB. The sum of ELISB and ELNIB represents a total of energy used to produce interstate and internationally traded electricity. The sum of ELNIB and ELISB may be positive or negative - positive values indicate that a state is a net importer (over the course of a year) of electricity and negative values indicate the state is a net exporter. In either case, the actual amount of energy that crosses state lines is only a fraction of this sum because of losses in the generation and transmission process.

The efficiency of the generation/transmission process is calculated as the ratio of the total amount of electricity consumed (reported under the data-code ESTCB) to the total amount of electricity produced. The total amount of electricity produced is calculated from the sum of the total amount of electricity consumed (again, ESTCB) and the total of energy losses in generation, transmission and distribution, represented by the SEDS data-code LOTCB.

$$\eta_{gen} = \frac{ESTCB}{ESTCB + LOTCB}$$

To find the actual amount of electricity transmitted into a state, we multiply the sum of ELNIB and ELISB by the generation efficiency.

When net imports are a negative number, the import flow is set to zero, and the total is multiplied by negative one and used by the *Electricity Exports* flow.

Electricity Exports: See above - Electricity exports are the negative of computed imports, and are set to zero when a state is a net importer.

Electricity Generation: The amount of electricity generated within a state is computed as the difference between the sum of electricity consumed and exported, and electricity imported. Each of these terms is described above, in this section of A.3.1.

$$Generation = (Use + Exports) - Imports$$

Rejected Energy from Electricity Production: The electricity sector rejects more than half of the energy it consumes. Energy rejection from the electricity sector is calculated as the difference between the total amount of energy input into the electricity sector (described above as SEDS data-codes TEEIB-ELNIB) and the total amount of electricity generated (described above as (*Use + Exports)-Imports)*).

$$Rejected\ Energy\ from\ Electricity = (TEEIB - ELNIB) - ((Use + Exports) - Imports)$$

Water Withdrawals for Thermoelectric Cooling: The total amount of water withdrawn for thermoelectric cooling within a state is reported in USGS Circular 1405 under the data-code PT_Wtotl. EIA also reports water withdrawals for thermoelectric cooling using a different methodology, and its statistics vary substantially from USGS's. It was determined that neither the 2010 USGS nor the 2010 EIA data were adequate to accurately represent water withdrawal for thermoelectric cooling.

The State Sankeys that are currently under development have a target data year of 2010. Since 2010, EIA has dramatically improved the quality of their withdrawal data with 2014 being the year we have full confidence in. 2014 is also the first year we have linked generation, boiler, and cooling data available. So, the purpose of this analysis is to adjust 2014 withdrawal data back to 2010. To accomplish this, EPSA used EIA 923, 860, and Water Cooling by Generator and Boiler data to account for generation and associated withdrawal additions and retirements in 2011, 2012, and 2013.
First new generation was calculated using the 2014 Water cooling by generator and boil summary data file. Second, generation retirements were calculated using the most recent 860 data file and 923 files from the year before generator retired. This adjustment introduces 3 main sources of uncertainty:

1. Overestimating generation additions
2. Withdrawal factors for retired generation
3. Operational changes in system due to retirements and additions

Only 1 and 2 in this list is examined in further detail below.

New Generators and Associated Withdrawal: The Water Cooling by Generator and Boiler Summary spreadsheet directly links generation and withdrawal. This was used to calculate withdrawal associated with generation additions. In the analysis spreadsheet, only withdrawal is reported, but this withdrawal was selected using new generators that were brought online between 2011 and 2013. This is complicated by the fact that many generators are added to plants with existing generators. So, unless there is a simple relationship (1 boiler, 1 cooling system, and 1 generator) there will be a range of dates for when all the generators at the plant were brought online. For example, if a plant has two generators, one with an in-service data of 1990 and another with and in-service data of 2012, this plant would show up using max in-service year, but would not show up using min in-service year.

The decision was made to select based on maximum generator in-service year. This means that some generation will be brought into the calculation that is attached to a generator that was installed outside of our selected range. Further analysis was performed to examine how this might impact the numbers.
The difference between using min gen in-service year and max gen in-service year is 2.2 BGD. With 2014 withdrawal reported to be 170 BGD, this represents an uncertainty of roughly 1% nationally. Maine, Texas, and Wisconsin are the only states where there is a significant difference between different methods. These 3 states account for 99% of the difference, with 7% in TX, 20% in WI, and 54% in ME.

Table A.2.5-1: three states with larges difference between min and max generation in-service year.

State	total withdrawal	Min Gen Inservice	Max Gen Inservice	Diff	% of Total Withdrawal
ME	84	-	45	45	54%
TX	20,276	9	1,391	1,382	7%
WI	4,050	-	799	799	20%

Considering these states in more depth, 62% of the difference can be attributed to the Oak Grove plant in TX, 36% is from the Elm Road Generating Station in Wisconsin, and 2% is from the Bucksport Generation LLC in ME. Each of these plants was examined closer. Each of the plants had 1 cooling system with either 2 or 3 generators. The withdrawal was adjusted based on the amount of generation from the generators that came online in 2011, 2012, or 2013.

Table A.2.5-2: Adjusted Plant Withdrawal

state	plant	relationship	origional withdrawal	adjusted withdrawal	generator in-service year
TX	Oak Grove (TX)	1C 2B 2G	1381	667	2011
WI	Elm Road Generating Station	1C 2B 2G	799	387	2011
ME	Bucksport Generation LLC	1C 4B 3G	45	5	2012

Generation Retirements and Associated Withdrawal: EIA 860 data was used to determine which generators were retired between 2011 and 2013. This information was then used in combination with EIA 923 data from the year prior to retirement to determine the amount of generation that was retired. Only steam generation was considered, as this accounted for 99% of the retired water using capacity. Of the steam generation that was retired, 93% was Conventional steam coal, 5% was natural gas steam turbine, and 1% was wood/wood waste biomass. Based on these numbers, a withdrawal factor of 35,000 gal/MWh was used to determine the amount of withdrawal from the generation.

Fresh Surface Water: Fresh surface water withdrawals for thermoelectric cooling were calculated as above, using EIA's source water categories of Fresh and Reclaimed Surface Water, as well as Discharged water.

Saline Surface Water: Saline surface water withdrawals for thermoelectric cooling were calculated as above, using EIA's source water categories of Saline and Brackish and Mixed Surface Water.

Fresh Groundwater: Fresh groundwater withdrawals for thermoelectric cooling were calculated as above, using EIA's source water categories of Fresh and Reclaimed Groundwater.

Saline Groundwater: Saline groundwater withdrawals for thermoelectric cooling were calculated as above, using EIA's source water categories of Saline and Brackish and Mixed Groundwater.

Where "other" or nothing were specified, the actual water source was used to determine the type and source. Missing withdrawal source and type were filled in according to where the water came from when available, and called fresh surface when not available.

Water Disposition from Thermoelectric Cooling: Water withdrawn for thermoelectric cooling may be returned to surface-water bodies, or it may be evaporated. The water use for generators discontinued before 2014 is determined from 2010-2014 generation retirements (retired steam 860). Generation was multiplied by 35,000 to get an estimate of gallons withdrawn and by 140 to get an estimate of gallons consumed.

The Water Discharge Name and definitions below (injection, surface, ocaean) were used to determine where water was discharged. Discharge was labeled as "surface" otherwise when it was impossible to determine. Discharge for each generator was calculated by subtracting consumption from withdrawal. Discharges were summed across state and type.

Injection: wells, aquifers

Surface: Pond, Lake, river, creek, multiple if not near ocean, municipal, city, reservoir, spring, gully other Chicago sanitary and ship, plant cooling system, host facility PD, other if source or discharge was one of above.

Ocean: ocean, sound, kill, bayou, ship channel, gulf bay, island channel, delta, inner coastal waterway, multiple if near ocean, other if source or discharge was one of above.

From retired steam 860, the 2010-2014 generation retirements data set was used to determine the water use for generators discontinued before 2014. Data from EviroequipY2010 and EviroequipY2011 that had water source and type but no discharge information was merged with 2010-2014 generation retirements (retired steam 860) by plant Code. The final retirements results were added to the results of the 2014 data minus the additions.

A.3.2 Public Water Supply

Energy Used for Municipal Water Treatment: Energy for treating and distributing drinking water is calculated from the estimated energy intensity of (1) withdrawal, (2) treatment and (3) distribution, as well as (4) the estimated total energy of long-distance conveyance to public suppliers in the western states. In this analysis, only electrical energy consumption is calculated. The energy intensities are multiplied by the quantities of water withdrawn. The energy intensity of withdrawal and treatment varies according to whether groundwater or surface water is used.

Surface Water Withdrawal Energy Intensity

Energy intensity of withdrawal for surface water is assumed constant throughout the United States and calculated as the energy needed to pressurize water to 13 psi at 65% efficiency. This figure is consistent with EPRI's estimate of 145 kW/MG. (EPRI, 2013)

Groundwater Withdrawal Energy Intensity

Energy intensity of withdrawal for groundwater is assumed to vary with the depth of groundwater. FRIS surveys request well characteristics of water pumped, including depth to water at the start of the irrigation season. The state's depth to water, as reported by FRIS, is converted into a pumping energy requirement (also assuming 65% efficiency), and added to the required power to pressurize the water to 13 psi. This figure is consistent with EPRI's estimate of 920 kWh/MG (when the state's groundwater depth is estimated to be 160 ft.)

Surface Water Treatment Energy Intensity

Energy intensity of treating surface water is assumed to be 405 kWh/MG. This figure is consistent with estimations from Tidwell of 1600 kWh/MG for the full energy intensity of SW withdrawal, treatment and distribution (assuming 1040 kWh/MG for distribution, see below; and 145 kWh/MG for withdrawal pumping, as above). It is also consistent with EPRI's estimate of the energy intensities of the most commonly used water treatment technologies for surface water.

Groundwater Treatment Energy Intensity

Energy intensity of treating groundwater is assumed to be 205 kWh/MG. This figure is consistent with estimations from Tidwell of 1400 kWh/MG for the full energy intensity of GW withdrawal, treatment and distribution (assuming 1040 kWh/MG for distribution, see below; and 145 kWh/MG for inlet pressurization, as above, and calculating the groundwater lift independently according to depth reported by FRIS). It is also consistent with EPRI's estimate of the energy intensities of the most commonly used water treatment technologies for ground water.

Distribution Energy Intensity

Energy intensity of water distribution is assumed to be 1040 kWh/MG, consistent with EPRI's estimate and corresponding to a treatment plant outlet pressure of 94 psi and a pump efficiency of 65%.

Conveyance Energy

Tidwell estimated the total energy used in each of 17 western states for long-distance water conveyance. It is assumed that all "conveyed" water is surface water. Furthermore, "conveyed" water is assumed to be used for both agricultural and public supply purposes. Tidwell's estimate of total conveyance energy, on a state-by-state basis, is pro-rated by the total quantities of surface water withdrawn by the agricultural (USGS data-code IR_WSWFr) and public supply sectors (USGS data-code PS_WSWFr). For the purposes of the energy used by public and municipal water suppliers, conveyance energy is calculated as Tidwell's gross state conveyance consumption multiplied by surface water withdrawals by public suppliers, divided by surface water withdrawals by both public suppliers and agricultural users.

$$Conveyance\ Energy_{public\ supply} = Conveyance\ Energy_{total} * \frac{PS\_WSWFr}{PS\_WSWFr + IR\_WSWFr}$$

Total Electricity Consumed by the Public Water Supply Sector

The total of electricity used by public and municipal suppliers is the total energy used to pump, treat and distribute groundwater, to pump, treat and distribute surface water, and, for the western states only, to convey water over long distances. The total energy used for groundwater is the quantity of groundwater withdrawn (USGS data-code PS_WGWFr, see below) multiplied by the sum of the energy intensities for groundwater withdrawal (pumping energy, see above), groundwater treatment (see above) and distribution (see above). Similarly, the total energy used for surface water is the quantity of surface water withdrawn (USGS data-code PS_WSWFr, see below) multiplied by the sum of the energy intensities for surface water withdrawal (see above), surface water treatment (see above) and distribution (see above). Conveyance energy is added to this total.

Disposition of Energy from Public and Municipal Water Treatment: The energy efficiency of the municipal water treatment sector is assumed to be the same as the energy efficiency of the commercial sector: 65%. This is roughly equivalent to the energy efficiency of water pumping as estimated by EPRI (EPRI, 2013), which is the largest use of electricity in the water treatment industry.

Energy Services: 65% of energy used by the water treatment sector (see above) is apportioned to energy services.

Rejected Energy: 35% of the energy used by the water treatment (see above) sector is apportioned to rejected energy.

Water Withdrawals for Public and Municipal Water Treatment: Water withdrawn for treatment and distribution through public and municipals suppliers is reported in USGS Circular 1405 under the data-code PS_Wtotl. As a cross-check, it is confirmed that this total is equivalent to the sum of resource-specific withdrawals for public supply from fresh and saline surface and groundwater supplies.

Fresh Surface Water: Fresh surface water withdrawals for public supply are reported in USGS Circular 1405 under the data-code PS_WSWFr. No assumptions or calculations are used to infer state-level fresh surface water withdrawal for public supply.

Saline Surface Water: Saline surface water withdrawals for public supply are reported in USGS Circular 1405 under the data-code PS_WSWSa. No assumptions or calculations are used to infer state-level saline surface water withdrawal for public supply. Saline surface water withdrawals for public supply are a very small fraction of total withdrawals for public supply.

Fresh Groundwater: Fresh groundwater withdrawals for public supply are reported in USGS Circular 1405 under the data-code PS_WGWFr. No assumptions or calculations are used to infer state-level fresh groundwater withdrawal for public supply.

Saline Groundwater: Saline groundwater withdrawals for public supply are reported in USGS Circular 1405 under the data-code PS_WGWSa. No assumptions or calculations are used to infer state-level saline groundwater withdrawal for public supply. Saline groundwater withdrawals for public supply are a very small fraction of total withdrawals for public supply.

Public Supply Water Use: Water withdrawn and treated by public and municipal suppliers is used in the residential, commercial and industrial sectors. The total amount of water used in these sectors is equivalent to the total amount of water withdrawn for public and municipal supply.

More information about the quantities of treated water used can be found in the following sections.

A.4.2 Treated water use in the residential sector

A.4.3 Treated water use in the commercial sector

A.4.4 Treated water use in the industrial sector

It is assumed that public water supply is not used in the agricultural sector, because water used for irrigation, livestock and aquaculture is subject to substantially different (lower) treatment standards than public supply.

A.3.3 Wastewater Treatment

Energy Used for Wastewater Treatment: In the preparation of this report, no data could be found to support a state-by-state analysis of energy used in the wastewater treatment industry. Rather, estimates of regional wastewater treatment energy intensity (from AWWA - See Appendix D) were used. These energy intensity estimates were multiplied by the quantity of wastewater received in each state. As a note, AWWA reported energy intensity on a primary energy basis - that is - the reported energy statistics include the energy content of resources used to produce electricity that is the main input to wastewater treatment plants.

Electricity Used in Wastewater Treatment: For each state, the quantity of wastewater received (see below - and sections A.4.2, A.4.3 and A.4.4) is multiplied by the reported energy intensity, converted back to an electricity (not primary) energy intensity.

Disposition of Energy Used for Wastewater Treatment: The energy efficiency of the wastewater treatment sector is assumed to be the same as the energy efficiency of the commercial sector: 65%. This is roughly equivalent to the energy efficiency of water pumping, which is the largest use of electricity in the wastewater treatment industry (EPRI, 2013).

Energy Services: 65% of energy used by the wastewater treatment sector (see above) is apportioned to energy services.

Rejected Energy: 35% of the energy used by the wastewater treatment (see above) sector is apportioned to rejected energy.

Water Delivered to Wastewater Treatment: The quantity of water delivered to the wastewater treatment sector in each state is calculated as the sum of the waters discharged by the residential, commercial and industrial sectors to the wastewater treatment sector. Calculations of each of these quantities are discussed below in sections:

A.4.2 Discharge to wastewater treatment from the residential sector

A.4.3 Discharge to wastewater treatment from the commercial sector

A.4.4 Discharge to wastewater treatment from the industrial sector

Water Discharged by Wastewater Treatment: The total quantity of water discharged by wastewater treatment plants is equivalent to the quantity of water discharged to wastewater treatment plants. Water may be discharged to surface water bodies or the ocean. It is assumed that municipal wastewater treatment facilities do not consume or inject water for disposal.

Ocean Discharge: For states without coastal exposure, discharge to the ocean is assumed to be zero. For states with coastal exposure, data supporting a quantitative state-by-state analysis of ocean discharge of treated wastewater was not available, however, a large fraction of the population lives close to the ocean, and discharge of treated wastewater to the ocean is a common practice. NOAA estimates that as of 2010, 39% of the nation's population lived in counties with coastal exposure. We estimate that, for states with coastal exposure, 50% of all treated wastewater is discharged to the ocean.

Surface Discharge: For states without coastal exposure, discharge of treated wastewater to the surface is equivalent to the total quantity of water received by wastewater treatment facilities. For states with coastal exposure, discharge of treated wastewater to the surface is calculated by subtracting the quantity of water discharged to the ocean from the total quantity of wastewater treated.

A.4 End Use

A.4.1 Transportation

Energy Use in the Transportation Sector: Energy consumption by the transportation sector is reported directly in SEDS under that data-code TNACB. No additional calculations or assumptions are used to infer transportation energy use. As a cross-check, it has been confirmed that TNACB is equivalent to the sum of petroleum, biofuel, natural gas and electricity energy uses within the transportation sector (see below).

Petroleum: Petroleum-based fuel use in the transportation sector is recorded by SEDS under the data-code PAACB. PAACB includes petroleum-based fuels, as well as the ethanol blended into the gasoline supply in E15 and E85 blends. Therefore, to calculate just the petroleum-based portion of energy consumption in the transportation sector, the total quantity of biofuels, reported under the data-code EMACB, is subtracted. Petroleum use in the transportation sector is calculated as the difference between PAACB and EMACB.

Biomass: Biofuel use in the transportation sector is recorded by SEDS under the data-code EMACB. No additional assumptions or calculations are used to infer state-level biomass use in the transportation sector beyond this value.

Natural Gas: Natural Gas use in the transportation sector is recorded by SEDS under the data-code NGACB. No assumptions or calculations are used to infer state-level natural gas use in the transportation sector beyond this value.

Coal: Coal use in the transportation sector is recorded by SEDS under the data-code CLACB. No assumptions or calculations are used to infer state-level coal use in the electricity sector beyond this value. In recent years, coal use in the transportation sector has been effectively zero.

Electricity: Electricity use in the transportation sector is recorded by SEDS under the data-code ESACB. No assumptions or calculations are used to infer state-level electricity use in the transportation sector beyond this value.

Disposition of Energy Used by the Transportation Sector: The energy efficiency of the transportation sector is assumed to be 21% - roughly the efficiency of conversion of fuel energy to propulsive work in the automotive, trucking, rail, shipping and aviation sub-sectors (LLNL 2010a).

Energy Services: 21% of energy used by the transportation sector (see above) is apportioned to energy services.

Rejected Energy: 79% of the energy used by the transportation sector (see above) sector is apportioned to rejected energy.

A.4.2 Residential

Energy Use in the Residential Sector: Energy consumption by the residential sector is reported directly in SEDS under that data-code TNRCB. No additional calculations or assumptions are used to infer residential energy use. As a cross-check, it has been confirmed that TNRCB is equivalent to the sum of petroleum, biomass, natural gas, geothermal, wind/solar and electricity energy uses within the residential sector (see below).

Petroleum: Petroleum use in the residential sector is recorded by SEDS under the data-code PARCB. No assumptions or calculations are used to infer state-level petroleum use in the residential sector beyond this value.

Biomass: Biomass use in the residential sector is recorded by SEDS under the data-code WDRCB. Most biomass use in the residential sector is from the burning of wood for heating purposes. Biofuels and other bioenergy use are a very small or non-existent fraction of residential energy use. No assumptions or calculations are used to infer state-level biomass use in the residential sector beyond this value.

Natural Gas: Natural Gas use in the residential sector is recorded by SEDS under the data-code NGRCB. No assumptions or calculations are used to infer state-level natural gas use in the residential sector beyond this value.

Coal: Coal use in the residential sector is recorded by SEDS under the data-code CLRCB. No assumptions or calculations are used to infer state-level coal use in the residential sector beyond this value. In recent years, coal use in the residential sector has been effectively zero.

Geothermal: Geothermal energy use in the residential sector is recorded by SEDS under the data-code GERCB. GERCB includes the thermal energy inputs into ground-source heat-pumps. No assumptions or calculations are used to infer state-level geothermal use in the residential sector beyond this value.

Wind and Solar: Solar energy use in the residential sector, including both solar-thermal heating and photovoltaic "behind the meter" electricity generation, are recorded directly by SEDS under the data-code SOHCB. Residential wind energy generation is not recorded by SEDS and assumed to be zero (small-scale wind energy is a negligible fraction of residential energy use). Therefore, the flow from wind and solar energy to the residential sector is equal to SOHCB.

Electricity: Consumption of electricity in the residential sector is recorded by SEDS under the data-code ESRCB. No additional assumptions or calculations are used to infer state-level electricity use in the residential sector.

Disposition of Energy Used by the Residential Sector: The energy efficiency of the residential sector is assumed to be 65%, as calculated by LLNL in 2010 (LLNL 2010b).

Energy Services: 65% of energy used by the residential sector (see above) is apportioned to energy services.

Rejected Energy: 35% of the energy used by the residential sector (see above) sector is apportioned to rejected energy.

Water Use in the Residential Sector: Water use by the residential sector is reported directly in USGS Circular 1405 under the data-code DO_TOTAL. No additional calculations or assumptions are used to infer residential energy use. As a cross-check, it has been confirmed that DO_TOTAL is equivalent to the sum of deliveries from public supplies and withdrawals from fresh surface and groundwater in the residential sector (see below). Saline surface and groundwater are not accessed directly by the residential sector.

Fresh Surface Water: Fresh surface water withdrawals by the residential sector are recorded in USGS Circular 1405 under the data-code DO_WSWFr. No assumptions or calculations are used to infer state-level fresh surface water withdrawals by residential sector beyond this value. Fresh surface water withdrawals are a very small component of residential water withdrawals.

Fresh Groundwater: Fresh groundwater withdrawals by the residential sector are recorded in USGS Circular 1405 under the data-code DO_WGWFr. No assumptions or calculations are used to infer state-level fresh surface water withdrawals by residential sector beyond this value.

Deliveries from Public Supply: Use of water supplied from public and municipal treatment plants is recorded in USGS Circular 1405 under the data-code DO_PSDel. No additional assumptions or calculations are used to infer state-level publically supplied residential sector.

Disposition of Water Used in the Residential Sector: Water used in the residential sector may be consumed, discharged to municipal wastewater treatment systems or discharged to the surface (usually through domestic septic systems). There are no recent estimates of consumptive use of water in the residential sector on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, a "residential consumptive fraction" CF_{res} was calculated from the ratio of residential water consumption to residential water use (self-supply plus municipal deliveries) in 1995.

Consumptive Use: Consumptive use of water in the residential sector occurs through evaporation of water in from domestic irrigation activities, water used for washing (that is not returned to drains) and drinking (and eventual respiration and perspiration) by individuals. The quantity of water consumed or evaporated in the residential sector is computed from the total quantity of water used in the residential sector (see above) multiplied by the residential consumptive use fraction (also above).

Discharge to Wastewater Treatment Facilities: For the purposes of this analysis, we have assumed that all homes served by public and municipal water suppliers are also served by municipal wastewater treatment facilities. There are exceptions to this rule (in sparsely populated suburban regions where homes use septic systems and are served by municipal suppliers), but they represent a relatively small fraction of the population. The quantity of water flowing from residences to wastewater treatment facilities is assumed to be the non-consumptive fraction ($1\text{-}CF_{res}$) multiplied by the quantity of municipally treated water flowing to residences (DO_PSDel - see above).

Surface Discharge: For residences that are not connected to municipal wastewater treatment systems, non-consumed water is discharged to the environment, usually through a septic system. In this analysis, surface discharge is calculated by subtracting both consumptive use and discharge to wastewater treatment from the total water used by residences.

A.4.3 Commercial

Energy Use in the Commercial Sector: Energy consumption by the commercial sector is reported directly in SEDS under that data-code TNCCB. No additional calculations or assumptions are used to infer commercial energy use. As a cross-check, it has been confirmed that TNCCB is equivalent to the sum of petroleum, biomass, natural gas, geothermal, hydro, wind/solar and electricity energy uses within the commercial sector (see below).

Petroleum: Petroleum-based fuel use in the commercial sector is recorded by SEDS under the data-code PACCB. PACCB includes petroleum-based fuels, as well as the ethanol blended into the gasoline supply in E15 and E85 blends. Therefore, to calculate just the petroleum-based portion of energy consumption in the commercial sector, the total quantity of biofuels, reported under the data-code EMCCB, is subtracted. Petroleum use in the Commercial sector is calculated as the difference between PACCB and EMCCB.

Biomass: Biomass use in the commercial sector is recorded by SEDS under the data-code WWCCB. This includes both wood and the bio-derived portion of waste that is burned for energy in commercial facilities. Additionally, the biofuel fraction of petroleum-based liquid fuels consumed by the commercial sector is recorded by SEDS under the data-code EMCCB. Biomass use in the commercial sector is calculated as the sum of WWCCB and EMCCB.

Natural Gas: Natural Gas use in the commercial sector is recorded by SEDS under the data-code NGCCB. No assumptions or calculations are used to infer state-level natural gas use in the commercial sector beyond this value.

Coal: Coal use in the commercial sector is recorded by SEDS under the data-code CLCCB. No assumptions or calculations are used to infer state-level coal use in the commercial sector beyond this value.

Geothermal: Geothermal energy use in the commercial sector is recorded by SEDS under the data-code GECCB. GECCB is a very small component of commercial energy use. No assumptions or calculations are used to infer state-level geothermal use in the commercial sector beyond this value.

Hydroelectricity: Hydroelectric generation operated by the commercial sector is recorded by SEDS under the data-code HYCCB. HYCCB is a very small component of commercial energy use. No assumptions or calculations are used to infer state-level direct hydroelectric use in the commercial sector beyond this value.

Wind and Solar: Solar energy use in the commercial sector, including both solar-thermal heating and photovoltaic electricity generation, is recorded directly by SEDS under the data-code SOCCB. SOCCB includes only commercial photovoltaic installations of 1MW capacity and larger (smaller commercial installations are lumped into residential solar energy use). Commercially owned wind-powered generation is recorded by SEDS under the data-code WYCCB. The flow from wind and solar energy to the commercial sector is the sum of SOCCB and WYCCB.

Electricity: Consumption of electricity in the commercial sector is recorded by SEDS under the data-code ESCCB. No additional assumptions or calculations are used to infer state-level electricity use in the commercial sector.

Disposition of Energy Used by the Commercial Sector: The energy efficiency of the commercial sector is assumed to be 65%. (LLNL 2013) Energy consuming activities in the commercial sector are similar to those used in the residential sector.

Energy Services: 65% of energy used by the commercial sector (see above) is apportioned to energy services.

Rejected Energy: 35% of the energy used by the commercial sector (see above) sector is apportioned to rejected energy.

Water Use in the Commercial Sector: In this analysis, all water use in the commercial sector is assumed to be attributed to public supply (see below).

Deliveries from Public Supply: Data on state-level use of water in the commercial sector has not been collected for the past 10 years. Therefore, numerous assumptions were made regarding water use in the commercial sector.

- The first assumption is that all water use in the commercial sector is delivered from public and municipal suppliers. No self-supplied water from surface or groundwater resources was considered. We assume that the fraction of non-agricultural, non-industrial business in rural areas not served by public suppliers is small.
- The second assumption is that all water deliveries from public and municipal suppliers can be accounted for between residential, commercial and industrial water users. It is assumed that public water supply is not used in the agricultural sector, because water used for irrigation, livestock and aquaculture is subject to substantially different (lower) treatment standards than public supply.
- The third assumption is that in each state, the ratio of water deliveries for commercial users to the water deliveries for industrial users has not changed substantially since the last time commercial water use was surveyed in 1995. This assumption is the most speculative.

To calculate water use in the commercial sector, we first calculated the quantity of publically and municipally treated water delivered to the commercial sector and industry as the difference between the total deliveries from the supply sector (PS_Wtotl) and the deliveries to the residential sector (DO_PSDel).

$$PS_{ind,comm} = PS\_Wtotl - DO\_PSDel$$

We then calculated the fraction of industrial and commercial water deliveries that were attributed to the commercial sector in 1995. This "commercial delivery fraction" (DF_{comm}) is a function of the commercial use of publically supplied water (CO_PSDel) and industrial use of publically supplied water (IN_PSDel).

$$DF_{comm} = \frac{CO\_PSDel_{1995}}{CO\_PSDel_{1995} + IN\_PSDel_{1995}}$$

Finally, we multiply the commercial delivery fraction by the deliveries to the commercial and industrial sector to calculate the use of publically and municipally treated water in the commercial sector (CO_PSDel)

$$CO\_PSDel_{2010} = PS_{ind,comm} * DF_{comm}$$

Disposition of Water Used in the Commercial Sector: Water used in the commercial sector may be consumed or discharged to municipal wastewater treatment systems. As above, we assume that all non-agricultural, non-industrial commercial entities are served by public water supplies and wastewater collection systems. With no available data, we cannot estimate the quantity of water used by commercial entities that is discharged through septic systems to local ground and surface water bodies. There are no recent estimates of consumptive use of water in the commercial sector on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, a "commercial consumptive fraction" CF_{comm} was calculated from the ratio of commercial water consumption to commercial water use (self-supply plus municipal deliveries) in 1995.

Consumptive Use: The quantity of water consumed or evaporated in the commercial sector is computed from the total quantity of water used in the commercial sector (see above) multiplied by the commercial consumptive use fraction (also above).

Discharge to Wastewater Treatment Facilities: For the purposes of this analysis, we have assumed that all commercial businesses are served by municipal wastewater treatment facilities. The quantity of water flowing from businesses to wastewater treatment facilities is calculated as the difference between total water use in the commercial sector (above) and consumptive use (also above).

A.4.4 Industrial

The boundaries of the industrial sector are not well defined across agencies that collect data on water and energy use. For the purposes of this analysis, the industrial sector includes heavy industry, manufacturing, mining and the non-irrigation aspects of farming and agriculture. Specifically excluded from industry in this analysis are the activities in agriculture related to irrigation, the water supply, treatment and delivery business, and the wastewater treatment enterprise. These sub-sectors are alternately included in industrial, mining, commercial and agricultural accounting, depending on the agency and data source.

Energy Use in the Industrial Sector: Almost every form of energy is used by industry to drive processes that move and transform natural resources, intermediate products and finished goods.

Petroleum: Petroleum-based product consumption in the industrial sector is recorded by SEDS under the data-code PAICB. PAICB includes petroleum-based fuels and feedstocks, as well as the ethanol blended into the gasoline supply in E15 and E85 blends. Therefore, to calculate just the petroleum-based portion of energy consumption in the industrial sector, the total quantity of biofuels, reported under the data-code EMICB, is subtracted. Petroleum use in the industrial sector is calculated as the difference between PAICB and EMICB.

Biomass: Biomass use in the industrial sector is recorded by SEDS under the data-code WWICB. This includes both wood and the bio-derived portion of waste that is burned for energy in industrial facilities. Additionally, the biofuel fraction of petroleum-based liquid fuels consumed by the industrial sector is recorded by SEDS under the data-code EMICB. Biomass use in the industrial sector is calculated as the sum of WWICB and EMICB.

Natural Gas: Natural Gas use in the industrial sector is recorded by SEDS under the data-code NGICB. No assumptions or calculations are used to infer state-level natural gas use in the industrial sector beyond this value.

Coal: Coal use in the industrial sector is recorded by SEDS under the data-code CLICB. No assumptions or calculations are used to infer state-level coal use in the industrial sector beyond this value.

Geothermal: Geothermal energy use in the commercial sector is recorded by SEDS under the data-code GEICB. No assumptions or calculations are used to infer state-level geothermal use in the industrial sector beyond this value.

Hydroelectricity: Hydroelectric generation operated by the industrial sector is recorded by SEDS under the data-code HYICB. No assumptions or calculations are used to infer state-level direct hydroelectric use in the industrial sector beyond this value.

Wind and Solar: Solar energy use in the industrial sector, including both solar-thermal heating and photovoltaic electricity generation, is recorded directly by SEDS under the data-code SOICB. SOCCB includes only industrial photovoltaic installations of 1MW capacity and larger (smaller industrial installations are lumped into residential solar energy use). Industrially owned wind-powered generation is recorded by SEDS under the data-code WYICB. The flow from wind and solar energy to the industrial sector is the sum of SOICB and WYICB.

Electricity: Consumption of electricity in the industrial sector is recorded by SEDS under the data-code ESICB. SEDS includes energy used in the agricultural sector, as well as energy used in water supply and treatment, and wastewater treatment into the industrial sector. For the purposes of this analysis, industrial consumption of electricity is calculated by subtracting electricity use in water treatment (see above in A.3.2), electricity use in wastewater treatment (see above in A.3.3) and electricity use in irrigation (see below in A.4.5) from ESICB.

Disposition of Energy Used by the Industrial Sector: The energy efficiency of the industrial sector is assumed to be 80%. (LLNL 2013)

Energy Services: 80% of energy used by the industrial sector (see above) is apportioned to energy services.

Rejected Energy: 20% of the energy used by the industrial sector (see above) sector is apportioned to rejected energy.

Water Use in the Industrial Sector: Water is used in industry as a coolant, a solvent, a washing fluid, a process input and myriad other purposes. Industry uses a diverse set of water resources to meet local needs and requirements. Furthermore, water is used in mining (a component of industry for the purposes of this analysis) for dust control and other applications. Energy-related mining activities (extraction of coal, oil and natural gas) are excluded from industrial water use because they are accounted for in the water withdrawals attributed to each of these resources. Total use of water in the industrial sector is defined as the sum of fresh surface water, saline surface water, fresh groundwater, saline groundwater and publically supplied water, each of which is defined below:

Fresh Surface Water: Fresh surface water withdrawals for industry are reported in USGS Circular 1405 under the data-code IN_WSWFr. Fresh surface water withdrawals for mining (including mining of energy resources) are reported in USGS Circular 1405 under the data-code MI_WSWFr. Fresh surface water withdrawals for petroleum, coal and natural gas extraction are calculated as above in sections A.1.1, A.1.3 and A.1.4 respectively. For the purposes of this analysis, fresh surface water withdrawals for industry (FSW_{ind}) are calculated as the sum of industrial (IN_WSWFr) and the difference between mining (MI_WSWFr) withdrawals, and the sum of oil- ($FSW_{petroleum}$), coal- (FSW_{coal}) and natural gas- (FSW_{NG}) related withdrawals.

$$FSW_{ind} = IN\_WSWFr + \left(MI\_WSWFr - \left(FSW_{petroleum} + FSW_{coal} + FSW_{NG}\right)\right)$$

However, because of account differences between USGS's calculation of water withdrawals for all mining activities, and NETL's calculation of water withdrawals for energy-related mining activities, if the term in parentheses is negative, it is assumed to be zero. Mismatches in mining water use do not impinge on non-mining use of water in the manufacturing industries.

Saline Surface Water: Saline surface water withdrawals for industry are reported in USGS Circular 1405 under the data-code IN_WSWSa. Saline surface water withdrawals for mining (including mining of energy resources) are reported in USGS Circular 1405 under the data-code MI_WSWSa. Saline surface water withdrawals for petroleum, coal and natural gas extraction are calculated as above in sections A.1.1, A.1.3 and A.1.4 respectively. For the purposes of this analysis, saline surface water withdrawals for industry (SSW_{ind}) are calculated as the sum of industrial (IN_WSWSa) and the difference between mining (MI_WSWSa) withdrawals, and the sum of oil- ($SSW_{petroleum}$), coal- (SSW_{coal}) and natural gas- (SSW_{NG}) related withdrawals.

$$SSW_{ind} = IN\_WSWSa + \left(MI\_WSWSa - \left(SSW_{petroleum} + SSW_{coal} + SSW_{NG}\right)\right)$$

However, because of account differences between USGS's calculation of water withdrawals for all mining activities, and NETL's calculation of water withdrawals for energy-related mining activities, if the term in parentheses is negative, it is assumed to be zero. Mismatches in mining water use do not impinge on non-mining use of water in the manufacturing industries.

Fresh Groundwater: Fresh groundwater withdrawals for industry are reported in USGS Circular 1405 under the data-code IN_WGWFr. Fresh groundwater withdrawals for mining (including mining of energy resources) are reported in USGS Circular 1405 under the data-code MI_WGWFr. Fresh groundwater withdrawals for petroleum, coal and natural gas extraction are calculated as above in sections A.1.1, A.1.3 and A.1.4 respectively. For the purposes of this analysis, fresh groundwater withdrawals for industry (FGW_{ind}) are calculated as the sum of industrial (IN_WGWFr) and the difference between mining (MI_WGWFr) withdrawals, and the sum of oil- ($FGW_{petroleum}$), coal- (FGW_{coal}) and natural gas- (FGW_{NG}) related withdrawals.

$$FGW_{ind} = IN\_WGWFr + \left(MI\_WGWFr - \left(FGW_{petroleum} + FGW_{coal} + FGW_{NG}\right)\right)$$

However, because of account differences between USGS's calculation of water withdrawals for all mining activities, and NETL's calculation of water withdrawals for energy-related mining activities, if the term in parentheses is negative, it is assumed to be zero. Mismatches in mining water use do not impinge on non-mining use of water in the manufacturing industries.

Saline Groundwater: Saline groundwater withdrawals for industry are reported in USGS Circular 1405 under the data-code IN_WGWSa. Saline groundwater withdrawals for mining (including mining of energy resources) are reported in USGS Circular 1405 under the data-code MI_WGWSa. Saline groundwater withdrawals for petroleum, coal and natural gas extraction are calculated as above in sections A.1.1, A.1.3 and A.1.4 respectively. For the purposes of this analysis, saline groundwater withdrawals for industry (SGW_{ind}) are calculated as the sum of industrial (IN_WGWSa) and the difference between mining (MI_WGWSa) withdrawals, and the sum of oil- ($SGW_{petroleum}$), coal- (SGW_{coal}) and natural gas- (SGW_{NG}) related withdrawals.

$$SGW_{ind} = IN\_WGWSa + \left(MI\_WGWSa - \left(SGW_{petroleum} + SGW_{coal} + SGW_{NG}\right)\right)$$

However, because of account differences between USGS's calculation of water withdrawals for all mining activities, and NETL's calculation of water withdrawals for energy-related mining activities, if the term in parentheses is negative, it is assumed to be zero. Mismatches in mining water use do not impinge on non-mining use of water in the manufacturing industries.

Deliveries from Public Supply: Data on state-level use of publically and municipally treated water in the industrial sector has not been reported for the past 10 years. Data on the total supply of centrally treated water is available for 2010, and data for public supply deliveries to residential users is available. To estimate public supply deliveries to industry, several assumptions were made:

- The first assumption is that *all* water use in the *commercial* sector (see section A.4.3 above) is delivered from public and municipal suppliers. No self-supplied water from surface or groundwater resources was considered for the commercial sector.
- The second assumption is that all water deliveries from public and municipal suppliers can be accounted for between residential, commercial and industrial water users. It is assumed that public water supply is not used in the agricultural sector, because water used for irrigation, livestock and aquaculture is subject to substantially different (lower) treatment standards than public supply.
- The third assumption is that in each state, the ratio of water deliveries for commercial users to the water deliveries for industrial users has not changed substantially since the last time commercial water use was surveyed in 1995. This assumption is the most speculative.

To calculate water use in the industrial sector, we first calculated the quantity of publically and municipally treated water delivered to the commercial sector and industry as the difference between the total deliveries from the supply sector (PS_Wtotl) and the deliveries to the residential sector (DO_PSDel).

$$PS_{ind,comm} = PS\_Wtotl - DO\_PSDel$$

We then calculated the fraction of industrial and commercial water deliveries that were attributed to the industrial sector in 1995. This "industrial delivery fraction" (DF_{ind}) is a function of the commercial use of publically supplied water (CO_PSDel) and industrial use of publically supplied water (IN_PSDel).

$$DF_{ind} = \frac{IN\_PSDel_{1995}}{CO\_PSDel_{1995} + IN\_PSDel_{1995}}$$

Finally, we multiply the industrial delivery fraction by the deliveries to the commercial and industrial sector to calculate the use of publically and municipally treated water in the industrial sector (IN_PSDel)

$$IN\_PSDel_{2010} = PS_{ind,comm} * DF_{ind}$$

Disposition of Water Used in the Industrial Sector: Water used in the industrial sector may be consumed, discharged to central wastewater treatment facilities, discharged to surface water supplies, discharged to the ocean or injected for permanent subsurface disposal. Calculation of the various components of industrial water disposition is complicated by the fact that this analysis includes mining water use and excludes mining water use from energy (oil, natural gas and coal) production activities.

Consumptive Use: There are no recent estimates of consumptive use of water in the industrial sector on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, a set of "industrial consumptive fractions" were calculated from the ratio of industrial water consumption to industrial water use in 1995. These fractions describe the consumptive use of freshwater ($CF_{ind,fr}$) and saline water ($CF_{ind,sa}$) in the non-mining industrial sector, as well as the consumptive use of freshwater ($CF_{mining,fr}$) and saline water ($CF_{mining,sa}$) in the mining sector. The total consumptive use of water in the industrial sector (CU_{ind}), as defined in this analysis, is calculated as the sum of the consumptive use in the non-mining industrial sector ($CU_{ind,non-mining}$) and the consumptive use in the non-energy mining sector ($CU_{mining,non-e}$). Each of these terms is defined as follows:

Consumptive use of water in the non-mining industrial sector is calculated from the from the quantities of fresh and saline surface and groundwater, and publically supplied water delivered to non-mining industry (IN_WSWFr, IN_WSWSa, IN_WGWFr, IN_WGWSa, IN_PSDel_{2010}, see above), and the consumptive use fractions in industry:

$$CU_{ind,non-mining} = CF_{ind,fr} * (IN\_WSWFr + IN\_WGWFr + IN\_PSDel_{2010}) + CF_{ind,sa} * (IN\_WSWSa + IN\_WGWSa)$$

Consumptive use of water in the non-energy mining sector is calculated from the from the quantities of fresh and saline surface and groundwater, delivered to non-energy mining operations (parenthetical terms in the expressions for SW_{ind}, SSW_{ind}, FGW_{ind}, SGW_{ind}, above), and the consumptive use fractions for the mining industry. Note that the parenthetical terms have been replaced here using the following nomenclature: $SGW_{mi,non-e}$ = MI_WGWSa - ($SGW_{petroleum}$ + SGW_{coal} + SGW_{NG}))

$$CU_{mining,non-e} = CF_{mining,fr} * \left(FSW_{mi,non-e} + FGW_{mining,non-e}\right) + CF_{mining,sa} * \left(SSW_{mining,non-e} + SGW_{mining,non-e}\right)$$

Finally, those two terms are summed to calculate consumptive use in the industrial sector as defined in this analysis:

$$CU_{ind} = CU_{ind,non-mining} + CU_{mining,non-e}$$

Discharge to Wastewater Treatment Facilities: There are no recent estimates of industrial water discharge to wastewater treatment facilities on a state-by-state basis for 2010. Therefore, several assumptions were made regarding the discharge of industrial water to public wastewater treatment systems. It was assumed that all self-supplied water, fresh and saline, surface and groundwater, was selftreated and disposed (see below). It was assumed that any water delivered from public and municipal supply that was *not consumed* was discharged to a wastewater treatment facility. Essentially, if it came from the municipality and wasn't consumed, then it went back to the municipality. It was also assumed that the consumptive fraction for municipally supplied water was equal to the consumptive fraction of industrially used freshwater in the last year for which data were available: 1995. Because public water supplies are not used in the mining industry, this calculation was somewhat less complex than the consumptive calculation for the entire industrial sector above. Discharge to wastewater treatment by industry ($DWWT_{ind}$) is the product of public supply deliveries to industry (IN_PSDel_{2010}, above) and the consumptive use fraction of freshwater in the non-mining industry ($CF_{ind,fr}$).

$$DWWT_{ind} = CF_{ind,fr} + IN\_PSDel_{2010}$$

Discharge to Ocean: There are no recent estimates of industrial water discharge to the ocean on a state-by-state basis for 2010. In this analysis, we assume that the vast majority of industrial discharge to the ocean occurs in large, urban areas where industrial use of fresh water is coupled to the municipal water and wastewater systems, and industrial withdrawal of saline water (primarily for cooling of industrial processes) is coupled back to the ocean. All the non-consumed saline water withdrawn in these states is discharged to the ocean. The quantity of consumed water is calculated via the use of the industrial consumptive fraction for saline water ($CF_{ind,sa}$, calculated from 1995 data as above). The quantity of water discharged to the ocean (DOC_{ind}) is then:

$$DOC_{ind} = CF_{ind,sa} * (IN\_WSWSa + IN\_WGWSa)$$

For states that do not border the ocean, ocean discharge is assumed to be zero. Given that non-energy mining operations are rarely located directly on the coast, the mining contribution to industrial ocean discharge is assumed to be zero.

Disposal via Injection: Data on industrial and non-energy mining disposal of water via underground injection on a state-by-state basis could not be located in time for incorporation into this report. It is assumed to be zero. A placeholder for this value ($DINJ_{ind}$) exists so that data can be incorporated into the analysis at a future time.

Discharge to Surface: Data on industrial and non-energy mining water discharges to the surface is not available. Instead, surface discharge by industry ($DSURF_{ind}$) is calculated as the difference between the sum of water withdrawals and deliveries in the industrial sector, and the sum of consumption, discharge to wastewater treatment, discharge to the ocean and disposal via injection.

$$DSURF_{ind} = \{FSW_{ind} + SSW_{ind} + FGW_{ind} + SGW_{ind} + IN\_PSDel_{2010ind}\} - (CU_{ind} + DWWT_{ind} + DOC_{ind} + DINJ_{ind})$$

A.4.5 Agriculture

Agriculture spans the energy-water nexus in two distinct ways: Energy is used to pump water to irrigate crops, and water is used to grow crops that are a feedstock for biofuels production. This analysis considers those two intersections separately. It also includes water for livestock and aquaculture.

Energy use in Agriculture: This analysis only considers the energy used to pump water to that supports agricultural activity (livestock, aquaculture and the irrigation of crops). Other energy used in the agricultural sector, such as the fuel used to operate farming equipment, is accounted for in the transportation and industrial sectors. Additionally, it should be noted that the energy used for irrigation is calculated for all crops, including the crops that serve as feedstocks for biofuels production. This stands in contrast to the analysis of water use (below) which explicitly excludes water use for bio-feedstock production.

Electricity Consumed in the Agriculture Sector: Electricity is used to pump, convey and pressurize water for the irrigation of crops and the support of livestock and aquaculture activities. The energy intensity of pumping and pressurizing water is calculated separately for groundwater (EI_{gw}) and surface water (EI_{sw})

for each state. USDA's Farm and Ranch Irrigation Survey (FRIS) provides state-by-state data on irrigation groundwater depth and average irrigation pressurization levels for irrigation within a state, enabling the calculation of pump electricity consumption (assuming a 65% pumping electrical efficiency). It is assumed that all agricultural uses of water (irrigation of food, feed and fiber crops, irrigation of biomass crops, support of livestock operation and support of aquaculture operations) has the same groundwater and surface water energy intensity.

Fresh surface water withdrawals for irrigation are reported in USGS Circular 1405 under the data-code IR_WSWFr. Similarly, fresh groundwater withdrawals for irrigation are represented by IR_WGWFr, fresh surface and groundwater for livestock are represented by LS_WSWFr and LSWGWFr respectively and fresh surface and groundwater withdrawals for aquaculture are represented by LA_WSWFr and LA_WGWFr (see below).

Electricity use for pumping (withdrawal) and pressurization ($E_{ag,pp}$) is therefore:

$$E_{ag,pp} = EI_{SW} * (IR\_WSWFr + LS\_WSWFr + LA\_WSWFr) + EI_{gw} * (IR\_WGWFr + LS\_WGWFr + LA\_WGWFr)$$

Additionally, in the 17 western states where water conveyance is a significant energy user, the portion of energy used to convey water for the agricultural sector was added to the total. Tidwell reports the electricity consumption for water conveyance in each of these states. That energy is pro-rated to the agricultural sector by assuming that all conveyance energy is split between deliveries to public and municipal suppliers (see above, section A.3.2) and irrigation. The fraction delivered to irrigation is assumed to be equal to the amount of water used for irrigation, divided by the sum of water used for irrigation and water used for public supply.

$$Conveyance\ Energy_{agriculture} = Conveyance\ Energy_{total} * \frac{IR\_WSWFr}{PS\_WSWFr + IR\_WSWFr}$$

For states not included in Tidwell's 17-state analysis, conveyance energy is assumed to be zero.

Total electricity use in the agriculture sector is the sum of electricity used for conveyance, and pumping and pressurization.

Disposition of Energy Used by the Agricultural Sector: The energy efficiency of the agricultural sector is assumed to be 65%. Energy consuming activities in the agricultural sector in this analysis are primarily attributable to water pumping, similar to the water treatment and wastewater treatment sectors.

Energy Services: 65% of energy used by the agricultural sector (see above) is apportioned to energy services.

Rejected Energy: 35% of the energy used by the agricultural sector (see above) sector is apportioned to rejected energy.

Water use in Agriculture: Water is used to irrigate crops and support livestock and aquaculture operations in the agriculture sector. In this analysis, water used in the irrigation of biomass crops (see above, Section A.1.2) is explicitly excluded from agricultural water use. Fresh surface and groundwater are used in the agricultural sector. Saline water is generally not compatible with agricultural applications. Water from public and municipal supplies is also not considered for agriculture. The total amount of water used in agriculture is the sum of fresh surface water and fresh groundwater used in agriculture (below)

Fresh Surface Water: Fresh surface water withdrawals for irrigation (including the irrigation of biofuel crops) are reported in USGS Circular 1405 under the data-code IR_WSWFr. Fresh surface water withdrawals for livestock operations are reported in USGS Circular 1405 under the data-code LS_WSWFr. Fresh surface water withdrawals for aquaculture operations are reported in USGS Circular 1405 under the data-code LA_WSWFr. Fresh surface water withdrawals for the irrigation of biomass crops (here denoted BIO_WSWFr) are calculated as above in section A.1.2. For the purposes of this analysis, fresh surface water withdrawals for agriculture (FSW_{ag}) are calculated as the sum of irrigation, livestock and aquaculture withdrawals minus withdrawals for the production of biomass.

$$FSW_{ag} = IR\_WSWFr + LS\_WSWFr + LA\_WSWFr - BIO\_WSWFr$$

Fresh Groundwater: Fresh groundwater withdrawals for irrigation (including the irrigation of biofuel crops) are reported in USGS Circular 1405 under the data-code IR_WGWFr. Fresh groundwater withdrawals for livestock operations are reported in USGS Circular 1405 under the data-code LS_WGWFr. Fresh groundwater withdrawals for aquaculture operations are reported in USGS Circular 1405 under the data-code LA_WGWFr. Fresh groundwater withdrawals for the irrigation of biomass crops (here denoted BIO_WGWFr) are calculated as above in section A.1.2. For the purposes of this analysis, fresh groundwater withdrawals for agriculture (FGW_{ag}) are calculated as the sum of irrigation, livestock and aquaculture withdrawals minus withdrawals for the production of biomass.

$$FGW_{ag} = IR\_WGWFr + LS\_WGWFr + LA\_WGWFr - BIO\_WGWFr$$

Disposition of Water in the Agriculture Sector: Water used in the agricultural sector is not discharged to public/municipal wastewater treatment facilities, discharged to the ocean or disposed via injection. Therefore, the only two modes of water disposition from the agricultural sector are consumption and surface discharge.

Consumptive Use: There are no recent estimates of consumptive use of water in the agricultural sector on a state-by-state basis, therefore, data on the consumptive use of water in 1995 was used to generate estimates of water disposition in recent years. For each state, a pair of "agricultural consumptive fractions" was calculated from the ratio of agricultural water consumption to total agricultural withdrawals in 1995. These fractions describe the consumptive use of water in the irrigation ($CF_{ag,ir}$) and livestock/aquaculture ($CF_{ag,lv}$) sub-sectors. The total consumptive use of water in the agricultural sector (CU_{ag}), as defined in this analysis, is calculated as the sum of the consumptive use in the irrigation and livestock/agriculture sub-sectors. Because disposition of water in the irrigation of biomass is accounted for elsewhere, biomass is excluded from this calculation (as above):

$$CU_{ag} = CF_{ag,ir} * (IR\_WSWFr - BIO\_WSWFr + IR\_WGWFr - BIO\_WGWFr) + CF_{ag,lv} * (LS\_WSWFr + LA\_WSWFr + LS\_WGWFr + LA\_WGWFr)$$

Surface Discharge: Surface discharge from agriculture (largely run-off from irrigation and livestock operations) is calculated as the difference between total withdrawals in the agriculture sector (see above) and consumptive use (also above).

A.5 Disposition

A.5.1 Energy Services

Energy services represent the fraction of all energy resources that are not converted to waste heat during transformations and application to end uses. Energy services are the sum of useful energy applied in the transportation, residential, commercial, industrial, water supply, wastewater treatment and agricultural sectors. The electricity sector does not produce energy services, rather, electricity is used for energy services in the aforementioned sectors. More information about each of these components can be found in preceding sections:

A.3.2 Energy Services delivered in the Public Water Supply Sector

A.3.3 Energy Services delivered in the Wastewater Treatment Sector

A.4.1 Energy Services delivered in the Transportation Sector

A.4.2 Energy Services delivered in the Residential Sector

A.4.3 Energy Services delivered in the Commercial Sector

A.4.4 Energy Services delivered in the Industrial Sector

A.4.5 Energy Services delivered in the Agricultural Sector

A.5.2 Rejected Energy

Rejected energy represents the fraction of all energy resources that are lost due to inefficiency (usually converted to waste heat) during energy transformations and application to end uses. The total amount of rejected energy in each state is the sum of rejected energy from the electricity generation, transportation, residential, commercial, industrial, water supply, wastewater treatment and agricultural sectors. More information about each of these components can be found in preceding sections:

A.3.1 Rejected Energy from the Electricity Generation Sector

A.3.2 Rejected Energy from the Public Water Supply Sector

A.3.3 Rejected Energy from the Wastewater Treatment Sector

A.4.1 Rejected Energy from the Transportation Sector

A.4.2 Rejected Energy from the Residential Sector

A.4.3 Rejected Energy from the Commercial Sector

A.4.4 Rejected Energy from the Industrial Sector

A.4.5 Rejected Energy from the Agricultural Sector

A.5.3 Surface Discharge

Surface discharge represents the total amount of water returned to surface water bodies such as lakes, rivers, as well as other discharges to the surface intended for evaporation or percolation into the shallow ground. Excluded from surface discharge are any transfers of water directly to the ocean. In this analysis, the total of surface discharge in each state is the sum of surface discharge from oil, natural gas and coal production, biomass production, thermoelectric cooling, the residential, commercial and industrial sectors, agriculture and wastewater treatment. It is assumed that public water suppliers do not discharge water. More information about each of these components can be found in the preceding sections:

A.1.1 Surface Discharge from Petroleum Production

A.1.2 Surface Discharge from Biomass Production

A.1.3 Surface Discharge from Natural Gas Production

A.1.4 Surface Discharge from Coal Production

A.3.1 Surface Discharge from Thermoelectric Cooling

A.3.3 Surface Discharge from the Wastewater Treatment Sector

A.4.2 Surface Discharge from the Residential Sector

A.4.3 Surface Discharge from the Commercial Sector

A.4.4 Surface Discharge from the Industrial Sector

A.4.5 Surface Discharge from the Agricultural Sector

A.5.4 Ocean Discharge

Ocean discharge represents the total amount of water intentionally discharged to the ocean from power plant, wastewater treatment and industrial outfalls. It is assumed that the agriculture sector does not discharge water to the ocean (irrigation and livestock-watering operations are generally not coastal activities), nor do the residential and commercial sectors. Furthermore, data on ocean discharges from offshore oil and natural gas operations was not incorporated into this analysis. In this analysis, the total of ocean discharge in each state is the sum of ocean discharge from thermoelectric cooling, the industrial sector, and wastewater treatment. More information about each of the included components can be found in the preceding sections:

A.3.1 Ocean Discharge from Thermoelectric Cooling

A.3.3 Ocean Discharge from the Wastewater Treatment Sector

A.4.4 Ocean Discharge from the Industrial Sector

A.5.5 Consumed Water

Water consumption represents the total amount of water evaporated, incorporated into products or otherwise temporarily or permanently removed from natural and engineered waterways. In this analysis, the total of consumed water in each state is the sum of consumed water in the production of oil, natural gas, coal, and biomass, thermoelectric cooling, the residential, commercial and industrial sectors, and the agricultural sector. More information about each of these components can be found in the preceding sections:

A.1.1 Consumption during Petroleum Production

A.1.2 Consumption during Biomass Production

A.1.3 Consumption during Natural Gas Production

A.1.4 Consumption during Coal Production

A.3.1 Consumption during Thermoelectric Cooling

A.4.2 Consumption in the Residential Sector

A.4.3 Consumption in the Commercial Sector

A.4.4 Consumption in the Industrial Sector

A.4.5 Consumption in the Agricultural Sector

A.5.6 Injected Water

Water is injected into the subsurface for waste disposal purposes in the industrial and oil and natural gas production sectors. Water is also injected into the subsurface during the drilling and completion of oil and natural gas wells, but this use of water is considered an input into the production of oil and natural gas. In this analysis, the total of injected water in each state is the sum of injected water in the industrial sector and in the production of oil and natural gas. More information about each of these components can be found in the preceding sections:

A.1.1 Injection for disposal during Petroleum Production

A.1.3 Injection for disposal during Natural Gas Production

A.4.4 Injection in the Industrial Sector

Appendix B – Data Sources

Appendix B is a dictionary of the source data codes, and definitions used in the energy-water analysis. The definitions are defined by EIA's State Energy Data System (SEDS), US Geological Survey (USGS), US Department of Agriculture (USDA) and US Energy Information Administration (EIA).

Appendix B.1 – State Energy Data System (SEDS)

The MSNs are five-character codes, most of which are structured as follows:

- First and second characters - describes an energy source (for example, NG for natural gas, MG for motor gasoline)
- Third and fourth characters - describes an energy sector or an energy activity (for example, RC for residential consumption, IC for industrial consumption, CC for commercial consumption, AC for transportation consumption, and PR for production)
- Fifth character - describes a type of data (for example, P for data in physical unit, B for data in billion Btu)

The complete data dictionary is omitted from this review copy for brevity. A copy can be accessed at: https://www.eia.gov/state/seds/CDF/Codes_and_Descriptions.xlsx

And a more extensive description of each code can be found in the .pdf documentation at: https://www.eia.gov/state/seds/seds-technical-notes-complete.php?sid=US

Appendix B.2 – USGS Data Dictionaries

Estimated Use of Water in the United States, Data Dictionary for County-Level Data for 2010 can be found at https://water.usgs.gov/watuse/data/2010/datadict.html

Estimated Use of Water in the United States, Data Dictionary for County-Level Data for 2005 can be found at https://water.usgs.gov/watuse/data/2005/datadict.html

Estimated Use of Water in the United States, Data Dictionary for 1995 Data Files can be found at https://water.usgs.gov/watuse/data/1995/datadict.html

The full dictionaries are omitted from this publication for brevity.

Appendix B.3 – USDA - National Agricultural Statistics Service (NASS) Data Dictionaries

USDA National Agricultural Statistics Service (NASS) Quickstats can be found at https://quickstats.nass.usda.gov/

For this report, we focused on the crops sector, and specifically corn field crops to identify:

- Corn grain Acres Harvested
- Corn grain Production
- Corn grain Yield

Appendix B.4 – USDA - Farm and Ranch Irrigation Survey (FRIS) Data Dictionaries

USDA's Farm and Ranch Irrigation Survey (FRIS) "is the most comprehensive source of information on irrigation water use throughout the agricultural industry and results are reported not only on the national and state levels, but by water resources regions."

The 2008 Farm and Ranch Irrigation Survey can be found at https://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/index.php

Tables of interest for the energy-water analysis include the following.

- Irrigated Farms by Acres Irrigated
- Estimated Quantity of Water Applied by Source or Supplier
- Crops Harvested from Irrigated Farms
- Estimated Quantity of Water Applied and Primary Method of Distribution by Selected Crops Harvested
- Irrigation Wells Used on Farms
- Energy Expenses for On-Farm Pumping of Irrigation Water by Water Source and Type of Energy
- Irrigation Pumps on Farms Other Than for Wells

The 2013 Farm and Ranch Irrigation Survey Can be found at https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/

Tables of interest for the energy-water analysis include the following.

- Crops Harvested in the Open from Irrigated Farms
- Land Irrigated in the Open by Method of Water Distribution
- Selected Crops Harvested in the Open by Chemigation and Water Source
- Estimated Quantity of Water Applied and Primary Method of Distribution by Selected Crops Harvested in the Open
- Characteristics of Irrigation Wells Used on Farms
- On-Farm Energy Expense for Pumping Irrigation Water by Water Source and Type of Energy
- Irrigation Pumps on Farms Other Than for Wells

Appendix B.5 – NETL Oil and Gas Water Withdrawal Quantities

B.5.1 – NETL Unconventional Oil and Gas Water Withdrawals

The National Energy Technology Laboratory (NETL) performed an analysis of water withdrawals for unconventional oil and gas production in the largest shale and tight oil and gas plays. These plays cover 12 of the largest unconventional oil producing states and 15 of the largest unconventional gas producing states.

	Fresh Surface Water Withdrawn for Unconventional Oil Production (MGD)	Fresh Groundwater Withdrawn for Unconventional Oil Production (MGD)	Fresh Surface Water Withdrawn for Unconventional Natural Gas Production (MGD)	Fresh Groundwater Withdrawn for Unconventional Natural Gas Production (MGD)
Arkansas	0.09	0.02	9.41	2.12
California	0.06	0.50	0.00	0.02
Colorado	4.76	1.07	11.39	2.56
Kansas	0.07	0.61	0.11	0.95
Louisiana	2.72	0.61	7.78	1.75
Montana	0.22	0.05	0.03	0.01
New Mexico	0.00	0.01	0.01	0.07
North Dakota	4.06	0.91	---	---
Ohio	0.00	0.00	0.05	0.00
Oklahoma	0.00	0.02	0.81	7.10
Pennsylvania	0.00	0.00	12.70	0.45
Texas	3.46	30.49	1.49	13.12
Utah	0.28	0.06	0.23	0.05
West Virginia	0.00	0.00	1.71	0.06
Wyoming	0.18	0.04	1.58	0.36

B.5.2 – Conventional Oil Water Withdrawals

The table below is reproduced from Wu et. al. (2011). The right-most column represents the water withdrawn per unit conventional oil produced.

PADD Region	Tech Weighted Average Injection	Produced Water to Oil Ratio	Percent of PW re-injected for recovery	PW used for Re-injection	Net Water need for injection
	gal/gal		%	gal/gal	gal/gal
I	8	9.8	99%	9.7	0.1
IA	8	9.8	99%	9.7	0.1
IB	8	9.8	99%	9.7	0.1
IC	8	9.8	99%	9.7	0.1
II	8	11.1	53%	5.9	2.1
III	8	10.9	52%	5.7	2.3
IV	8	14.7	92%	13.5	0.1
V	8	3.4	76%	2.6	5.4
NA	8	9.8	99%	9.7	0.1

Appendix C: Data Management and Visualization Methodology

Data File and Data Dictionaries – Appendix C provides a data dictionary that defines all data fields plotted on the hybrid Sankey diagrams, and provides a key to the variables contained in the associated Excel and CSV data files. The data covers source values that appear on the Sankey diagram in the process boxes, and water and energy flow data that connects the sources and end use boxes on the Sankey diagram. The data files, which contain data for 2005 and 2010, will be made publicly available along with this report.

Notes:

- LLB (LiveLink Box) variables are live linked to process boxes, and LLF (LiveLink Flow) variables are live linked to energy or water flow lines
- Units for water use = Mgal/d, units for energy use = Trillions of BTU per year

Table C- 1 - Hybrid Sankey Diagram Variable Data Dictionary

Description	Field Name
Agriculture Energy Use (Irrigation, Livestock and Aquaculture)	LLB_AgE
Agriculture Water Use (Irrigation, Livestock and Aquaculture less corn grain ethanol)	LLB_AgW
Biomass Energy Consumed	LLB_BioE
Biomass Energy Produced	LLB_BioProd
Biomass Water Use	LLB_BioW
Coal Energy Consumed	LLB_CoalE
Coal Energy Produced	LLB_CoalProd
Coal Water Use	LLB_CoalW
Commercial Energy Use	LLB_CommE
Commercial Water Use	LLB_CommW
In-State Electricity Generation	LLB_ElecGen
Thermoelectric Cooling Water Use	LLB_ElecW
Rejected Energy	LLB_EnRej
Fresh Ground Water	LLB_FGW
Fresh Surface Water	LLB_FSW
Natural Gas Energy Consumed	LLB_GasE
Natural Gas Energy Produced	LLB_GasProd
Natural Gas Water Use	LLB_GasW
Geothermal Energy	LLB_GeoE
Hydro Energy	LLB_HydroE
Nuclear Energy	LLB_NucE
Ocean Discharge	LLB_OcDisch

Description	Field Name
Petroleum Energy Consumed	LLB_OilE
Petroleum Energy Produced	LLB_OilProd
Petroleum Water Use	LLB_OilW
Public Water Supply Energy Use	LLB_PSE
Public Water Supply	LLB_PSW
Residential Energy Use	LLB_ResE
Residential Water Use	LLB_ResW
Saline Ground Water	LLB_SGW
Solar and Wind (combined)	LLB_SolWindE
Saline Surface Water	LLB_SSW
Surface Discharge	LLB_SurfDisch
Transportation Energy Use	LLB_TransE
Consumed Water	LLB_WCons
Injected Water	LLB_WInj
Wastewater Treatment Energy Use	LLB_WWE
Wastewater Treatment Water Flow	LLB_WWW
Flow: Agriculture Rejected (from 'Agriculture Irrigation, Aquaculture and Livestock' to 'Rejected Energy')	LLF_AgE_to_EnRej
Flow: Agriculture Services (from 'Agriculture Irrigation, Aquaculture and Livestock' to 'Energy Services')	LLF_AgE_to_EnSvc
Flow: Ag/Irrigation to Ocean Discharge (from 'Water Use' to 'Ocean Discharge')	LLF_AgW_to_OcDisch
Flow: Ag/Irrigation to Surface Water Discharge (from 'Water Use' to 'Surface Discharge')	LLF_AgW_to_SurfDisch
Flow: Ag/Irrigation to Consumed Water (from 'Water Use' to 'Consumed Water')	LLF_AgW_to_WCons
Flow: Ag/Irrigation to Injection (from 'Water Use' to 'Injection')	LLF_AgW_to_WInj
Flow: Irrigation Wastewater (from 'Water Use' to 'Water Flow ')	LLF_AgW_to_WWW
Flow: Biomass Commercial (from 'Consumption' to 'Commercial')	LLF_BioE_to_CommE
Flow: Biomass Electricity (from 'Consumption' to 'Electricity Generation')	LLF_BioE_to_ElecGen
Flow: Biomass Industrial (from 'Consumption' to 'Industrial')	LLF_BioE_to_IndE
Flow: Biomass Residential (from 'Consumption' to '')	LLF_BioE_to_ResE
Flow: Biomass Transportation (from 'Consumption' to 'Transportation')	LLF_BioE_to_TransE
Flow: Biomass to Wastewater Treatment (from 'Consumption' to 'Wastewater Treatment ')	LLF_BioE_to_WWE
Flow: Biomass to Ocean Discharge (from 'Bio Water Use' to 'Ocean Discharge')	LLF_BioW_to_OcDisch
Flow: Biomass to Surface Water Discharge (from 'Bio Water Use' to 'Surface Discharge')	LLF_BioW_to_SurfDisch
Flow: Biomass to Consumed Water (from 'Bio Water Use' to 'Consumed Water')	LLF_BioW_to_WCons
Flow: Biomass to Injection (from 'Bio Water Use' to 'Injection')	LLF_BioW_to_WInj
Flow: Biomass Wastewater (from 'Bio Water Use' to 'Water Flow ')	LLF_BioW_to_WWW
Flow: Coal Commercial (from 'Consumption' to 'Commercial')	LLF_CoalE_to_CommE
Flow: Coal Electricity (from 'Consumption' to 'Electricity Generation')	LLF_CoalE_to_ElecGen
Flow: Coal Industrial (from 'Consumption' to 'Industrial')	LLF_CoalE_to_IndE

Description	Field Name
Flow: Coal Residential (from 'Consumption' to '')	LLF_CoalE_to_ResE
Flow: Coal to Wastewater Treatment (from 'Consumption' to 'Wastewater Treatment ')	LLF_CoalE_to_WWE
Flow: Coal Production to Ocean Discharge (from 'Coal Water Use' to 'Ocean Discharge')	LLF_CoalW_to_OcDisch
Flow: Coal to Surface Water Discharge (from 'Coal Water Use' to 'Surface Discharge')	LLF_CoalW_to_SurfDisch
Flow: Coal Production to Consumed Water (from 'Coal Water Use' to 'Consumed Water')	LLF_CoalW_to_WCons
Flow: Coal Production to Injection (from 'Coal Water Use' to 'Injection')	LLF_CoalW_to_WInj
Flow: Coal Wastewater (from 'Coal Water Use' to 'Water Flow ')	LLF_CoalW_to_WWW
Flow: Commercial Rejected (from 'Commercial' to 'Rejected Energy')	LLF_CommE_to_EnRej
Flow: Commercial Services (from 'Commercial' to 'Energy Services')	LLF_CommE_to_EnSvc
Flow: Commercial to Ocean Discharge (from 'Comm. Water Use' to 'Ocean Discharge')	LLF_CommW_to_OcDisch
Flow: Commercial to Surface Water Discharge (from 'Comm. Water Use' to 'Surface Discharge')	LLF_CommW_to_SurfDisch
Flow: Commercial to Consumed Water (from 'Comm. Water Use' to 'Consumed Water')	LLF_CommW_to_WCons
Flow: Commercial to Injection (from 'Comm. Water Use' to 'Injection')	LLF_CommW_to_WInj
Flow: Commercial Wastewater (from 'Comm. Water Use' to 'Water Flow ')	LLF_CommW_to_WWW
Flow: Electricity to Agriculture (from 'Electricity Connector' to 'Agriculture Irrigation, Aquaculture and Livestock')	LLF_ElecConn_to_AgE
Flow: Electricity Commercial (from 'Electricity Connector' to 'Commercial')	LLF_ElecConn_to_CommE
Flow: Electricity Net Exports (from 'Electricity Connector' to ' ')	LLF_ElecConn_to_ElecExp
Flow: Electricity Industry (from 'Electricity Connector' to 'Industrial')	LLF_ElecConn_to_IndE
Flow: Electricity to Public Water Supply (from 'Electricity Connector' to 'Public and Municipal Water Supply')	LLF_ElecConn_to_PSE
Flow: Electricity Residential (from 'Electricity Connector' to '')	LLF_ElecConn_to_ResE
Flow: Electricity Transportation (from 'Electricity Connector' to 'Transportation')	LLF_ElecConn_to_TransE
Flow: Electricity to Wastewater Treatment (from 'Electricity Connector' to 'Wastewater Treatment ')	LLF_ElecConn_to_WWE
Flow: Domestic Electricity (from 'Electricity Generation' to 'Electricity Connector')	LLF_ElecGen_to_ElecConn
Flow: Electricity Rejected (from 'Electricity Generation' to 'Rejected Energy')	LLF_ElecGen_to_EnRej
Flow: Electricity Net Imports (from 'Electricity Net Imports' to 'Electricity Connector')	LLF_ElecImp_to_ElecConn
Flow: Thermoelectric to Ocean Discharge (from 'Thermo-electric Cooling' to 'Ocean Discharge')	LLF_ElecW_to_OcDisch
Flow: Thermoelectric to Surface Water Discharge (from 'Thermo-electric Cooling' to 'Surface Discharge')	LLF_ElecW_to_SurfDisch
Flow: Thermoelectric to Consumed Water (from 'Thermo-electric Cooling' to 'Consumed Water')	LLF_ElecW_to_WCons
Flow: Thermoelectric to Injection (from 'Thermo-electric Cooling' to 'Injection')	LLF_ElecW_to_WInj
Flow: Fresh Ground Water to Irrigation (from 'Fresh Ground' to 'Water Use')	LLF_FGW_to_AgW
Flow: Fresh Ground Water to Biomass (from 'Fresh Ground (2)' to 'Bio Water Use')	LLF_FGW_to_BioW

Description	Field Name
Flow: Fresh Ground Water to Coal Production (from 'Fresh Ground (2)' to 'Coal Water Use')	LLF_FGW_to_CoalW
Flow: Fresh Ground Water to Commercial (from 'Fresh Ground' to 'Comm. Water Use')	LLF_FGW_to_CommW
Flow: Fresh Ground Water to Thermoelectric (from 'Fresh Ground' to 'Thermo-electric Cooling')	LLF_FGW_to_ElecW
Flow: Fresh Ground Water to Natural Gas Production (from 'Fresh Ground (2)' to 'NG Water Use')	LLF_FGW_to_GasW
Flow: Fresh Ground Water to Industrial (from 'Fresh Ground' to 'Ind. Water Use')	LLF_FGW_to_IndW
Flow: Fresh Ground Water to Oil Production (from 'Fresh Ground (2)' to 'Water Use')	LLF_FGW_to_OilW
Flow: Fresh Ground Water to Public Supply (from 'Fresh Ground' to 'Water Flow')	LLF_FGW_to_PSW
Flow: Fresh Ground Water to Residential (from 'Fresh Ground' to 'Water Use')	LLF_FGW_to_ResW
Flow: Fresh Surface Water to Irrigation (from 'Fresh Surface' to 'Water Use')	LLF_FSW_to_AgW
Flow: Fresh Surface Water to Biomass (from 'Fresh Surface (2)' to 'Bio Water Use')	LLF_FSW_to_BioW
Flow: Fresh Surface Water to Coal Production (from 'Fresh Surface (2)' to 'Coal Water Use')	LLF_FSW_to_CoalW
Flow: Fresh Surface Water to Commercial (from 'Fresh Surface' to 'Comm. Water Use')	LLF_FSW_to_CommW
Flow: Fresh Surface Water to Thermoelectric Cooling (from 'Fresh Surface' to 'Thermo-electric Cooling')	LLF_FSW_to_ElecW
Flow: Fresh Surface Water to Natural Gas Production (from 'Fresh Surface (2)' to 'NG Water Use')	LLF_FSW_to_GasW
Flow: Fresh Surface Water to Industrial (from 'Fresh Surface' to 'Ind. Water Use')	LLF_FSW_to_IndW
Flow: Fresh Surface Water to Oil Production (from 'Fresh Surface (2)' to 'Water Use')	LLF_FSW_to_OilW
Flow: Fresh Surface Water to Public Supply (from 'Fresh Surface' to 'Water Flow')	LLF_FSW_to_PSW
Flow: Fresh Surface Water to Residential (from 'Fresh Surface' to 'Water Use')	LLF_FSW_to_ResW
Flow: Natural Gas Commercial (from 'Consumption' to 'Commercial')	LLF_GasE_to_CommE
Flow: Natural Gas Electricity (from 'Consumption' to 'Electricity Generation')	LLF_GasE_to_ElecGen
Flow: Natural Gas Industrial (from 'Consumption' to 'Industrial')	LLF_GasE_to_IndE
Flow: Natural Gas Residential (from 'Consumption' to '')	LLF_GasE_to_ResE
Flow: Natural Gas Transportation (from 'Consumption' to 'Transportation')	LLF_GasE_to_TransE
Flow: Natural Gas to Wastewater Treatment (from 'Consumption' to 'Wastewater Treatment ')	LLF_GasE_to_WWE
Flow: Natural Gas Production to Ocean Discharge (from 'NG Water Use' to 'Ocean Discharge')	LLF_GasW_to_OcDisch
Flow: Natural Gas to Surface Water Discharge (from 'NG Water Use' to 'Surface Discharge')	LLF_GasW_to_SurfDisch
Flow: Natural Gas Production to Consumed Water (from 'NG Water Use' to 'Consumed Water')	LLF_GasW_to_WCons
Flow: Natural Gas Production to Injection (from 'NG Water Use' to 'Injection')	LLF_GasW_to_WInj
Flow: Natural Gas Wastewater (from 'NG Water Use' to 'Water Flow ')	LLF_GasW_to_WWW
Flow: Geothermal Commercial (from 'Geothermal' to 'Commercial')	LLF_GeoE_to_CommE
Flow: Geothermal Electricity (from 'Geothermal' to 'Electricity Generation')	LLF_GeoE_to_ElecGen
Flow: Geothermal Industrial (from 'Geothermal' to 'Industrial')	LLF_GeoE_to_IndE

Description	Field Name
Flow: Geothermal Residential (from 'Geothermal' to '')	LLF_GeoE_to_ResE
Flow: Geothermal Transportation (from 'Geothermal' to 'Transportation')	LLF_GeoE_to_TransE
Flow: Coal Transportation (from 'Consumption' to 'Transportation')	LLF_CoalE_to_TransE
Flow: Geothermal to Wastewater Treatment (from 'Geothermal' to 'Wastewater Treatment ')	LLF_GeoE_to_WWE
Flow: Hydro Commercial (from 'Hydro' to 'Commercial')	LLF_HydroE_to_CommE
Flow: Hydro Electricity (from 'Hydro' to 'Electricity Generation')	LLF_HydroE_to_ElecGen
Flow: Hydro Industrial (from 'Hydro' to 'Industrial')	LLF_HydroE_to_IndE
Flow: Hydro Residential (from 'Hydro' to '')	LLF_HydroE_to_ResE
Flow: Hydro Transportation (from 'Hydro' to 'Transportation')	LLF_HydroE_to_TransE
Flow: Hydro to Wastewater Treatment (from 'Hydro' to 'Wastewater Treatment ')	LLF_HydroE_to_WWE
Flow: Industrial Rejected (from 'Industrial' to 'Rejected Energy')	LLF_IndE_to_EnRej
Flow: Industrial Services (from 'Industrial' to 'Energy Services')	LLF_IndE_to_EnSvc
Flow: Industrial to Ocean Discharge (from 'Ind. Water Use' to 'Ocean Discharge')	LLF_IndW_to_OcDisch
Flow: Industrial to Surface Water Discharge (from 'Ind. Water Use' to 'Surface Discharge')	LLF_IndW_to_SurfDisch
Flow: Industrial to Consumed Water (from 'Ind. Water Use' to 'Consumed Water')	LLF_IndW_to_WCons
Flow: Industrial to Injection (from 'Ind. Water Use' to 'Injection')	LLF_IndW_to_WInj
Flow: Industrial Wastewater (from 'Ind. Water Use' to 'Water Flow ')	LLF_IndW_to_WWW
Flow: Nuclear Commercial (from 'Nuclear' to 'Commercial')	LLF_NucE_to_CommE
Flow: Nuclear Electricity (from 'Nuclear' to 'Electricity Generation')	LLF_NucE_to_ElecGen
Flow: Nuclear Industrial (from 'Nuclear' to 'Industrial')	LLF_NucE_to_IndE
Flow: Nuclear Residential (from 'Nuclear' to '')	LLF_NucE_to_ResE
Flow: Nuclear Transportation (from 'Nuclear' to 'Transportation')	LLF_NucE_to_TransE
Flow: Nuclear to Wastewater Treatment (from 'Nuclear' to 'Wastewater Treatment ')	LLF_NucE_to_WWE
Flow: Petroleum Commercial (from 'Consumption' to 'Commercial')	LLF_OilE_to_CommE
Flow: Petroleum Electricity (from 'Consumption' to 'Electricity Generation')	LLF_OilE_to_ElecGen
Flow: Petroleum Industrial (from 'Consumption' to 'Industrial')	LLF_OilE_to_IndE
Flow: Petroleum Residential (from 'Consumption' to '')	LLF_OilE_to_ResE
Flow: Petroleum Transportation (from 'Consumption' to 'Transportation')	LLF_OilE_to_TransE
Flow: Petroleum to Wastewater Treatment (from 'Consumption' to 'Wastewater Treatment ')	LLF_OilE_to_WWE
Flow: Oil Production to Ocean Discharge (from 'Water Use' to 'Ocean Discharge')	LLF_OilW_to_OcDisch
Flow: Oil Production to Surface Water Discharge (from 'Water Use' to 'Surface Discharge')	LLF_OilW_to_SurfDisch
Flow: Oil Production to Consumed Water (from 'Water Use' to 'Consumed Water')	LLF_OilW_to_WCons
Flow: Oil Production to Injection (from 'Water Use' to 'Injection')	LLF_OilW_to_WInj
Flow: Petroleum Wastewater (from 'Water Use' to 'Water Flow ')	LLF_OilW_to_WWW
Flow: Public Supply to Rejected (from 'Public and Municipal Water Supply' to 'Rejected Energy')	LLF_PSE_to_EnRej
Flow: Public Water Supply Services (from 'Public and Municipal Water Supply' to 'Energy Services')	LLF_PSE_to_EnSvc

Description	Field Name
Flow: Public Supply to Irrigation (from 'Water Flow' to 'Water Use')	LLF_PSW_to_AgW
Flow: Public Supply to Commercial (from 'Water Flow' to 'Comm. Water Use')	LLF_PSW_to_CommW
Flow: Public Supply to Industrial (from 'Water Flow' to 'Ind. Water Use')	LLF_PSW_to_IndW
Flow: Public Supply to Ocean Discharge (from 'Water Flow' to 'Ocean Discharge')	LLF_PSW_to_OcDisch
Flow: Public Supply to Residential (from 'Water Flow' to 'Water Use')	LLF_PSW_to_ResW
Flow: Public Supply to Surface Water Discharge (from 'Water Flow' to 'Surface Discharge')	LLF_PSW_to_SurfDisch
Flow: Public Supply to Consumed Water (from 'Water Flow' to 'Consumed Water')	LLF_PSW_to_WCons
Flow: Public Supply to Injection (from 'Water Flow' to 'Injection')	LLF_PSW_to_WInj
Flow: Residential Rejected (from '' to 'Rejected Energy')	LLF_ResE_to_EnRej
Flow: Residential Services (from '' to 'Energy Services')	LLF_ResE_to_EnSvc
Flow: Residential to Ocean Discharge (from 'Water Use' to 'Ocean Discharge')	LLF_ResW_to_OcDisch
Flow: Residential to Surface Water Discharge (from 'Water Use' to 'Surface Discharge')	LLF_ResW_to_SurfDisch
Flow: Residential to Consumed Water (from 'Water Use' to 'Consumed Water')	LLF_ResW_to_WCons
Flow: Residential to Injection (from 'Water Use' to 'Injection')	LLF_ResW_to_WInj
Flow: Residential Wastewater (from 'Water Use' to 'Water Flow ')	LLF_ResW_to_WWW
Flow: Saline Ground Water to Irrigation (from 'Saline Ground' to 'Water Use')	LLF_SGW_to_AgW
Flow: Saline Ground Water to Biomass (from 'Saline Ground (2)' to 'Bio Water Use')	LLF_SGW_to_BioW
Flow: Saline Ground Water to Coal Production (from 'Saline Ground (2)' to 'Coal Water Use')	LLF_SGW_to_CoalW
Flow: Saline Ground Water to Commercial (from 'Saline Ground' to 'Comm. Water Use')	LLF_SGW_to_CommW
Flow: Saline Ground Water to Thermoelectric (from 'Saline Ground' to 'Thermo-electric Cooling')	LLF_SGW_to_ElecW
Flow: Saline Ground Water to Natural Gas Production (from 'Saline Ground (2)' to 'NG Water Use')	LLF_SGW_to_GasW
Flow: Saline Ground Water to Industrial (from 'Saline Ground' to 'Ind. Water Use')	LLF_SGW_to_IndW
Flow: Saline Ground Water to Oil Production (from 'Saline Ground (2)' to 'Water Use')	LLF_SGW_to_OilW
Flow: Saline Ground Water to Public Supply (from 'Saline Ground' to 'Water Flow')	LLF_SGW_to_PSW
Flow: Saline Ground Water to Residential (from 'Saline Ground' to 'Water Use')	LLF_SGW_to_ResW
Flow: Wind/Solar Commercial (from 'Wind/Solar' to 'Commercial')	LLF_SolWindE_to_CommE
Flow: Wind/Solar Electricity (from 'Wind/Solar' to 'Electricity Generation')	LLF_SolWindE_to_ElecGen
Flow: Wind/Solar Industrial (from 'Wind/Solar' to 'Industrial')	LLF_SolWindE_to_IndE
Flow: Wind/Solar Residential (from 'Wind/Solar' to '')	LLF_SolWindE_to_ResE
Flow: Wind/Solar Transportation (from 'Wind/Solar' to 'Transportation')	LLF_SolWindE_to_TransE
Flow: Wind/Solar to Wastewater Treatment (from 'Wind/Solar' to 'Wastewater Treatment ')	LLF_SolWindE_to_WWE
Flow: Saline Surface Water to Irrigation (from 'Saline Surface' to 'Water Use')	LLF_SSW_to_AgW
Flow: Saline Surface Water to Biomass (from 'Saline Surface (2)' to 'Bio Water Use')	LLF_SSW_to_BioW
Flow: Saline Surface Water to Coal Production (from 'Saline Surface (2)' to 'Coal Water Use')	LLF_SSW_to_CoalW

Description	Field Name
Flow: Saline Surface Water to Commercial (from 'Saline Surface' to 'Comm. Water Use')	LLF_SSW_to_CommW
Flow: Saline Surface Water to Thermoelectric (from 'Saline Surface' to 'Thermo-electric Cooling')	LLF_SSW_to_ElecW
Flow: Saline Surface Water to Natural Gas Production (from 'Saline Surface (2)' to 'NG Water Use')	LLF_SSW_to_GasW
Flow: Saline Surface Water to Industrial (from 'Saline Surface' to 'Ind. Water Use')	LLF_SSW_to_IndW
Flow: Saline Surface Water to Oil Production (from 'Saline Surface (2)' to 'Water Use')	LLF_SSW_to_OilW
Flow: Saline Surface Water to Public Supply (from 'Saline Surface' to 'Water Flow')	LLF_SSW_to_PSW
Flow: Saline Surface Water to Residential (from 'Saline Surface' to 'Water Use')	LLF_SSW_to_ResW
Flow: Transportation Rejected (from 'Transportation' to 'Rejected Energy')	LLF_TransE_to_EnRej
Flow: Transportation Services (from 'Transportation' to 'Energy Services')	LLF_TransE_to_EnSvc
Flow: Wastewater Treatment to Rejected (from 'Wastewater Treatment ' to 'Rejected Energy')	LLF_WWE_to_EnRej
Flow: Wastewater Treatment to Services (from 'Wastewater Treatment ' to 'Energy Services')	LLF_WWE_to_EnSvc
Flow: Wastewater Treatment to Ocean Discharge (from 'Water Flow ' to 'Ocean Discharge')	LLF_WWW_to_OcDisch
Flow: Wastewater Treatment to Surface Water Discharge (from 'Water Flow ' to 'Surface Discharge')	LLF_WWW_to_SurfDisch
Flow: Wastewater Treatment to Consumed Water (from 'Water Flow ' to 'Consumed Water')	LLF_WWW_to_WCons
Flow: Wastewater Treatment to Injection (from 'Water Flow ' to 'Injection')	LLF_WWW_to_WInj

Appendix D: Geographic Regions

This appendix includes the definitions and diagrams showing geographic regions of the U.S. that have been identified in the data files, for the purpose of filtering and examining the data by region. These include: USDA Regions, US Census Regions, the Petroleum Administration for Defense Districts (PADD) divisions, and the Federal Regional offices.

Figure D- 1 USDA Farm Production Regions

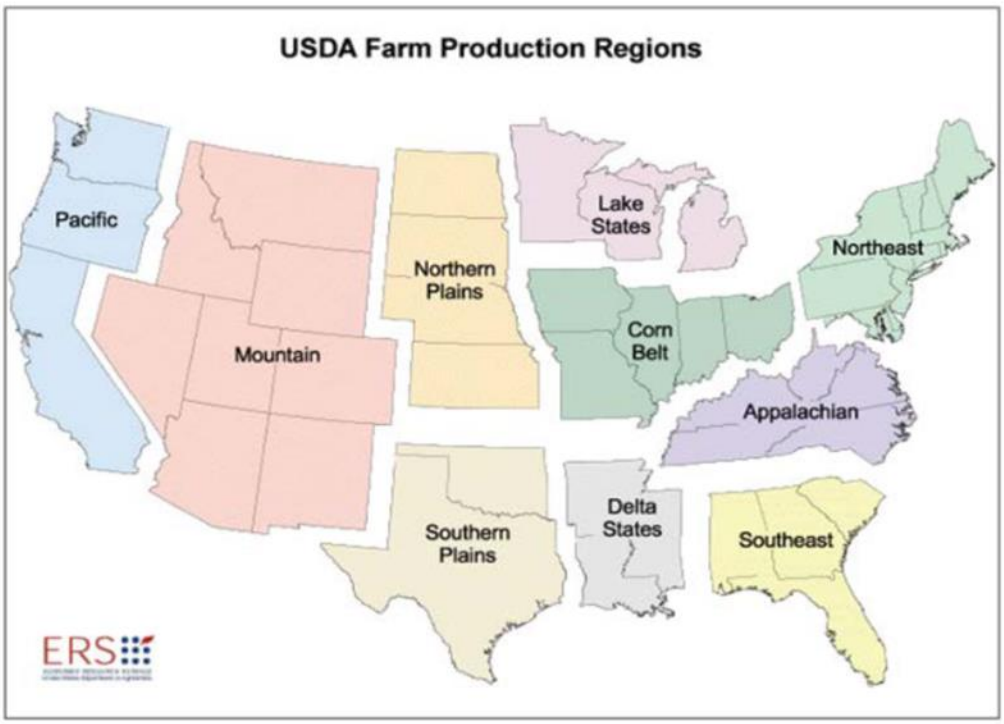


Figure D- 2 U.S. Census Regions

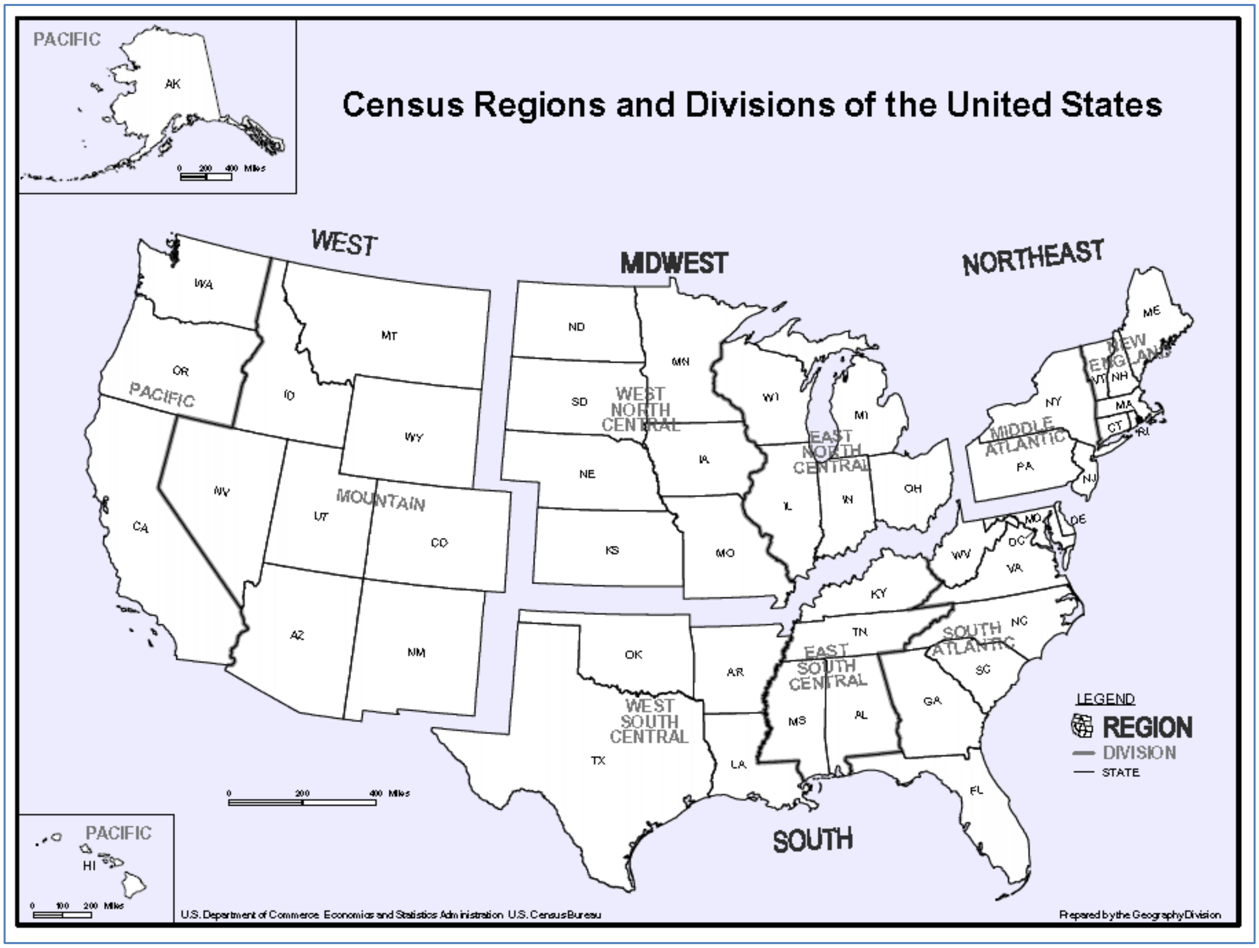


Figure D- 3 Petroleum Administration for Defense Districts (PADD) divisions

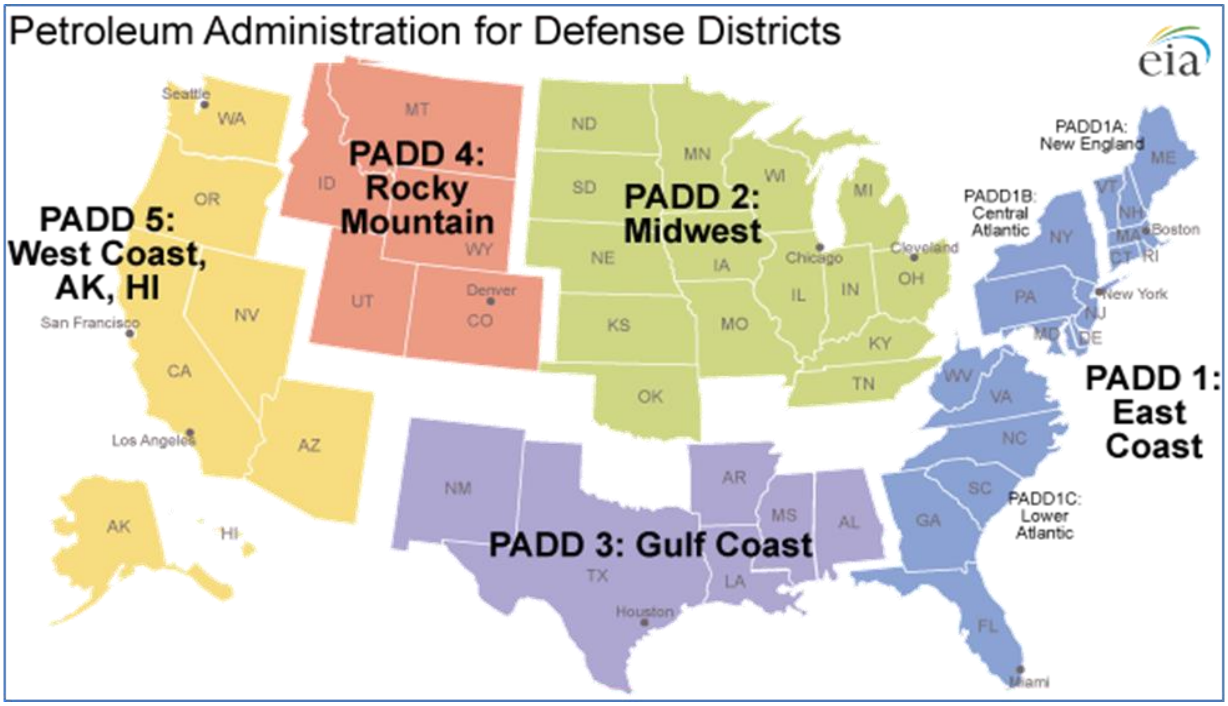


Table D- 1- Regions Defined for use in Filtering the Data Tables

Abbrev	USDA Region No	USDA Region Name	Census Region No	Census Region Name	PADD No	PADD Division Name	Federal Region No	Regional Office Name	AWWA Region No	AWWA Region Name
AK	0	Not Included	4	West	V	West Coast	10	Seattle	V	West
AL	3	Southeast	3	South	III	Gulf Coast	4	Atlanta	III	South
AR	4	Delta States	3	South	III	Gulf Coast	6	Dallas	III	South
AZ	9	Mountain	4	West	V	West Coast	9	San Francisco	IV	Southwest
CA	10	Pacific	4	West	V	West Coast	9	San Francisco	V	West
CO	9	Mountain	4	West	IV	Rocky Mountains	8	Denver	IV	Southwest
CT	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
DC	1	Northeast	3	South	NA	Not Included	3	Philadelphia	III	South
DE	1	Northeast	3	South	IB	Central Atlantic	3	Philadelphia	III	South
FL	3	Southeast	3	South	IC	Lower Atlantic	4	Atlanta	III	South
GA	3	Southeast	3	South	IC	Lower Atlantic	4	Atlanta	III	South
HI	0	Not Included	4	West	V	West Coast	9	San Francisco	V	West
IA	5	Corn Belt	2	Midwest	II	Midwest	7	Kansas City	II	Midwest
ID	9	Mountain	4	West	IV	Rocky Mountains	10	Seattle	IV	Southwest
IL	5	Corn Belt	2	Midwest	II	Midwest	5	Chicago	II	Midwest
IN	5	Corn Belt	2	Midwest	II	Midwest	5	Chicago	II	Midwest
KS	7	Northern Plains	2	Midwest	II	Midwest	7	Kansas City	II	Midwest
KY	2	Appalachian	3	South	II	Midwest	4	Atlanta	III	South
LA	4	Delta States	3	South	III	Gulf Coast	6	Dallas	III	South
MA	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
MD	1	Northeast	3	South	IB	Central Atlantic	3	Philadelphia	I	Northeastern
ME	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
MI	6	Lake States	2	Midwest	II	Midwest	5	Chicago	II	Midwest
MN	6	Lake States	2	Midwest	II	Midwest	5	Chicago	II	Midwest
MO	5	Corn Belt	2	Midwest	II	Midwest	7	Kansas City	IV	Southwest

Abbrev	USDA Region No	USDA Region Name	Census Region No	Census Region Name	PADD No	PADD Division Name	Federal Region No	Regional Office Name	AWWA Region No	AWWA Region Name
MS	4	Delta States	3	South	III	Gulf Coast	4	Atlanta	III	South
MT	9	Mountain	4	West	IV	Rocky Mountains	8	Denver	V	West
NC	2	Appalachian	3	South	IC	Lower Atlantic	4	Atlanta	III	South
ND	7	Northern Plains	2	Midwest	II	Midwest	8	Denver	II	Midwest
NE	7	Northern Plains	2	Midwest	II	Midwest	7	Kansas City	IV	Southwest
NH	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
NJ	1	Northeast	1	Northeast	IB	Central Atlantic	2	New York	I	Northeastern
NM	9	Mountain	4	West	III	Gulf Coast	6	Dallas	IV	Southwest
NV	9	Mountain	4	West	V	West Coast	9	San Francisco	V	West
NY	1	Northeast	1	Northeast	IB	Central Atlantic	2	New York	I	Northeastern
OH	5	Corn Belt	2	Midwest	II	Midwest	5	Chicago	II	Midwest
OK	8	Southern Plains	3	South	II	Midwest	6	Dallas	II	Midwest
OR	10	Pacific	4	West	V	West Coast	10	Seattle	V	West
PA	1	Northeast	1	Northeast	IB	Central Atlantic	3	Philadelphia	I	Northeastern
RI	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
SC	3	Southeast	3	South	IC	Lower Atlantic	4	Atlanta	III	South
SD	7	Northern Plains	2	Midwest	II	Midwest	8	Denver	II	Midwest
TN	2	Appalachian	3	South	II	Midwest	4	Atlanta	III	South
TX	8	Southern Plains	3	South	III	Gulf Coast	6	Dallas	IV	Southwest
UT	9	Mountain	4	West	IV	Rocky Mountains	8	Denver	IV	Southwest
VA	2	Appalachian	3	South	IC	Lower Atlantic	3	Philadelphia	III	South
VT	1	Northeast	1	Northeast	IA	New England	1	Boston	I	Northeastern
WA	10	Pacific	4	West	V	West Coast	10	Seattle	V	West
WI	6	Lake States	2	Midwest	II	Midwest	5	Chicago	II	Midwest
WV	2	Appalachian	3	South	IC	Lower Atlantic	3	Philadelphia	II	Midwest
WY	9	Mountain	4	West	IV	Rocky Mountains	8	Denver	IV	Southwest

Appendix E: Glossary

E.1 Water Use Terminology

E.1.1 USGS Water Use Terminology

The following terms have been used in one or more of the USGS water-use Circulars. The comparison of water-use categories over the history of these reports may also help clarify the use of some of the terms.

Animal-specialties water use - water use associated with the production of fish in captivity except for fish hatcheries which were in Commercial, and the raising of horses and such fur-bearing animals as rabbits and pets.

- 1985: Fish farming included in Livestock
- 1990-1995: Animal specialties (excludes fish hatcheries)
- 2000 and later: former Animal specialties use reported in Livestock (horses) and Aquaculture categories (fish hatcheries and fish farms)

See also aquaculture water use, fish-hatchery water use, livestock water use, and rural water use.

Aquaculture water use - water use associated with the farming of finfish, shellfish, and other organisms that live in water, and off-stream water use associated with fish hatcheries.

- 1985: Water use for fish farming included in Livestock
- 1990-1995: Water use was reported in Animal Specialties (fish farming) and Commercial (fish hatcheries)
- 2000 and later: Aquaculture

See also animal-specialties water use, commercial water use, and livestock water use, and Methods for Estimating Water Withdrawals for Aquaculture in the United States, 2005.

Closed-loop cooling system - *see* recirculation cooling system.

Commercial water use - water for motels, hotels, restaurants, office buildings, other commercial facilities, military and nonmilitary institutions, and (for 1990 and 1995) off-stream fish hatcheries. Water may be obtained from a public-supply system or may be self-supplied. Commercial water-use estimates were included in industrial water use until 1985, then were reported as a separate category. Commercial water use estimates were last reported nationally for 1995.

- 1985: Self-supplied commercial water use first reported as separate category from industrial

- 1990-1995: Commercial category includes off-stream fish hatchery water use for some States
- 2000 and later: Commercial category not estimated nationally: off-stream fish hatchery water use is reported in the Aquaculture category

See also fish-hatchery water use, public-supply water use, public-supply deliveries, industrial water use, and self-supplied water use.

Consumptive use **-** the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use. Water returned to a different watershed than the point of withdrawal (interbasin transfer) is ***not*** considered a consumptive use. Also referred to as water consumed.

- 1960-1995: Consumptive use reported by water-use category
- 2000 and later: Consumptive use not estimated nationally

Conveyance loss - water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation. Leakage from an irrigation ditch, for example, may percolate to a groundwater source and be available for further use.

- 1955-1995: Conveyance losses reported nationally
- 2000 and later: Conveyance losses not estimated nationally

See also irrigation water use.

Cooling-system type - an equipment system that provides water for cooling purposes, such as to condensers at power plants or at factories, subdivided into once-through or recirculation cooling system. *See also* industrial water use, once-through cooling system, recirculation cooling system, and thermoelectric-power water use.

Domestic water use - water used for indoor household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and outdoor purposes such as watering lawns and gardens. Domestic water use includes potable and non-potable water provided to households by a public water supplier (domestic deliveries) and self-supplied water.

- 1950-1955: Rural (included Livestock: estimates were retroactively allocated to Rural Domestic and Livestock in later reports)
- 1960-1980: Rural Domestic
- 1985 and later: Domestic

See also public-supply deliveries, public-supply water use, rural water use, and self-supplied water use.

Fish-hatchery water use **-** *See* aquaculture water use, commercial water use, and animal specialties water use.

Freshwater - water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids. Generally, water with more than 500 mg/L of dissolved solids is undesirable for drinking and many industrial uses. *See also* saline water.

Fuel-electric power - *see thermoelectric power water use*.

Hydroelectric power water use - the use of water in the generation of electricity at plants where the turbine generators are driven by moving water. Hydroelectric water use is most commonly an instream use. Hydroelectric power water use was referred to as water power from 1950-1960.

- 1950-1960: Water Power
- 1965-1995: Hydroelectric Power
- 2000 and later: Hydroelectric Power category not estimated nationally

Industrial water use - water used for fabrication, processing, washing, and cooling. Includes industries such as chemical and allied products, food, mining, paper and allied products, petroleum refining, and steel.

- 1950: Industrial, included thermoelectric power use
- 1955: Industrial, included thermoelectric power use, subtotals for thermoelectric power use (fuel-electric power) and other provided by watershed but not by State
- 1960-1980: Industrial, included thermoelectric power use, subtotals for thermoelectric power use (fuel-electric power) and "other industrial" uses
- 1985 and later: Industrial. Separate categories for thermoelectric power, self-supplied commercial and mining split from other industrial. The term industrial water use was used 1985-1995 to describe the combined public-supply deliveries to industrial users and self-supplied industrial withdrawals.

See also thermoelectric-power water use, commercial water use, mining water use, public-supply deliveries, public-supply water use, and self-supplied water use.

Instream use - water that is used, but not withdrawn, from a surface-water source for such purposes as hydroelectric-power generation, navigation, water-quality improvement, fish propagation, and recreation. Instream uses may change the flow characteristics or increase evaporative losses due to impoundments and release schedules. Instream water-use estimates for hydroelectric power were included in some previous water-use circulars but were omitted for 2000 to present.

Interbasin transfer - A transfer of water from one river basin to another. Interbasin transfers may be tracked or regulated for different levels of watersheds such as a hydrologic unit level or a set of basin delineations made by a regulatory authority.

Irrigation water use - water that is applied by an irrigation system to assist crop and pasture growth, or to maintain vegetation on recreational lands such as parks and golf courses. Irrigation includes water that is applied for pre-irrigation, frost protection, chemical application, weed control, field preparation, harvesting, dust suppression, leaching of salts from the root zone.

Irrigation water use estimates also include conveyance losses. *See also* conveyance loss, microirrigation system, sprinkler irrigation system, and surface irrigation system.

Livestock water use - water used for livestock watering, feedlots, dairy operations, and other on-farm needs. Types of livestock include dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses and poultry.

- 1950: Rural (included self-supplied domestic: estimates were allocated to Rural Domestic and Livestock in later reports)
- 1960-1980: Livestock subcategory under Rural
- 1985: Livestock, including water use for fish farming
- 1990-1995: Livestock. Subcategory of Animal Specialties included horses and fish farming
- 2000 and later: Livestock. Separate category of Aquaculture includes fish farming and fish hatcheries

See also animal-specialties water use, aquaculture water use, and rural water use, and Method for Estimating Water Withdrawals for Livestock in the United States, 2005.

Microirrigation system - an irrigation system that wets only a discrete portion of the soil surface in the vicinity of the plant by means of applicators (such as orifices, emitters, porous tubing, or perforated pipe) and operated under low pressure. The applicators may be placed on or below the surface of the ground or suspended from supports. *See also* irrigation water use, sprinkler irrigation system, and surface irrigation system.

Mining water use - water used for the extraction of naturally occurring minerals including solids (such as coal, sand, gravel, and other ores), liquids (such as crude petroleum), and gases (such as natural gas). Also includes uses associated with quarrying, milling and other preparations customarily done at the mine site, injection of water for secondary oil recovery or for unconventional oil and natural gas recovery (such as hydraulic fracturing), and other operations associated with mining activity. Does not include water associated with dewatering of the aquifer that is not put to beneficial use. Also does not include water used in processing, such as smelting, refining petroleum, or slurry pipeline operations. These processing uses are included in industrial water use.

- 1950-1980: included in Industrial
- 1985 and later: Mining

See also industrial water use and self-supplied water use, and Methods for Estimating Water Withdrawals for Mining in the United States, 2005.

Municipal water use - public supply water use. Term used in 1950 water-use circular.

North American Industry Classification System (NAICS) - a classification system used by Federal statistical agencies to classify establishments according to type of production or other economic activity. NAICS was adopted in 1997 to replace the Standard Industrial Classification system.

Off-stream use - water withdrawn or diverted from a groundwater or surface-water source for aquaculture, commercial, domestic self-supply, industrial, irrigation, livestock, mining, public supply, thermoelectric power, and other uses**.** *See also* entries for each of these categories of use.

Once-through cooling system - also known as open-loop cooling system. Cooling system in which the water is withdrawn from a source, circulated through the heat exchangers, and then returned to a body of water at a higher temperature. *See also* cooling system, cooling-system type, industrial water use, and thermoelectric-power water use.

Public-supply deliveries - amount of water delivered from a public supplier to users for domestic, commercial, industrial, thermoelectric-power, or public-use purposes.

- 1960-1965: combined estimate of deliveries for industrial and commercial use broken down by air conditioning and other, and combined estimate for domestic deliveries and losses
- 1970-1975: combined estimate of deliveries for industrial and commercial use, and combined estimate for domestic use and losses
- 1980: combined estimate of deliveries for industrial and commercial use, and combined estimate for domestic and public use including losses
- 1985-1995: estimates of deliveries for domestic, commercial, industrial, thermoelectric power, and public use and losses
- 2000: no estimates of deliveries
- 2005 and later: estimates of deliveries for domestic use and a combined estimate of all other uses and system losses

See also commercial water use, domestic water use, industrial water use, public-supply water use, public water use, and thermoelectric-power use.

Public-supply water use - water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric-power, and public water use. *See also* commercial water use, domestic water use, industrial water use, public-supply deliveries, public water use, and thermoelectric-power water use.

- 1950: Municipal
- 1955 and later: Public Supply

Public water use - water supplied from a public supplier and used for such purposes as firefighting, street washing, flushing of water lines, and maintaining municipal parks and swimming pools. Generally, public-use water is not billed by the public supplier. *See also* public-supply deliveries and public-supply water use.

Recirculation cooling system - also known as closed-loop cooling system. Water is withdrawn from a source, circulated through heat exchangers, cooled, and then re-used in the same process. Recirculation cooling systems may use induced draft cooling towers, forced draft cooling towers, cooling ponds, or canals. *See also* cooling system, cooling-system type, industrial water use, and thermoelectric-power water use.

Reclaimed wastewater **-** wastewater-treatment plant effluent that has been diverted for beneficial uses such as irrigation, industry, or thermoelectric cooling instead of being released to a natural waterway or aquifer. *See also* water use.

Return flow - water that reaches a groundwater or surface-water source after release from the point of use and thus becomes available for further use. Term used in previous water-use circulars. *See also* water use.

Rural water use - self-supplied water used in suburban or farm areas for domestic and livestock needs, and includes domestic use, drinking water for livestock, and other uses such as dairy sanitation, cleaning, and waste disposal.

- 1950-1955: Rural, included self-supplied domestic and livestock uses
- 1960-1980: Rural, subcategories of rural domestic and livestock
- 1985 and later: replaced by Domestic and Livestock categories

See also animal-specialties water use, domestic water use, livestock water use, and self-supplied water use.

Saline water - water that contains 1,000 mg/L or more of dissolved solids. *See also* freshwater.

Self-supplied water use - water withdrawn from a groundwater or surface-water source by a user rather than being obtained from a public supply.

Sprinkler irrigation system **-** an irrigation system in which water is applied by means of perforated pipes or nozzles operated under pressure so as to form a spray pattern. *See also* irrigation water use, microirrigation system, and surface irrigation system.

Standard Industrial Classification (SIC) codes - four-digit codes established by the Office of Management and Budget, published in 1987, and used in the classification of establishments by type of activity in which they are engaged; Largely replaced by the North American Industry Classification System (NAICS).

Surface irrigation system **-** Irrigation by means of flood, furrow, or gravity. Flood irrigation is the application of irrigation water in which the entire soil surface is covered by ponded water. Furrow is a partial surface-flooding method of irrigation normally used with clean-tilled crops in which water is applied in furrows or rows of sufficient capacity to contain the design irrigation stream. Gravity is an irrigation method in which water is not pumped, but flows in ditches or pipes and is distributed by gravity. *See also* irrigation water use, microirrigation system, and sprinkler irrigation system.

Thermoelectric-power water use - water used in the process of generating electricity with steam-driven turbine generators. Term used in previous water-use circulars to describe the combined public-supply deliveries to thermoelectric-power plants and self-supplied thermoelectric-power withdrawals.

- 1950: Included in Industrial
- 1955: Fuel-electric power subcategory in Industrial (data presented by watershed but not by State)
- 1960-1980: Fuel-electric power subcategory in Industrial
- 1985-1995: Thermoelectric power, subcategories by fuel type (fossil fuel, geothermal, nuclear)
- 2000 and later: Thermoelectric power, subcategories by cooling-system type (once-through, closed-loop/recirculation)

See also cooling system, cooling-system type, public-supply water use, industrial water use, and self-supplied water use, and methods for estimating water consumption for thermoelectric power plants in the United States.

Wastewater-treatment return flow - water returned to the hydrologic system by wastewater-treatment facilities. Wastewater-treatment return flows were referred to as sewage treatment in 1985. Wastewater treatment return flows were last reported in 1995. *See also* water use.

Water power, waterpower - hydroelectric power water use

Water use - In a restrictive sense, the term refers to water that is withdrawn for a specific purpose, such as for public supply, domestic use, irrigation, thermoelectric-power cooling, or industrial processing. In previous water-use circulars, water use for the domestic, commercial, industrial, and thermoelectric categories included both self-supplied withdrawals and deliveries from public supply. More broadly, water use pertains to the interaction of humans with and influence on the hydrologic cycle, and includes elements such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and instream use. *See also* off-stream use and instream use.

Water withdrawal **-** water removed from the ground or diverted from a surface-water source for use. *See also* off-stream use and self-supplied water.

E.1.2 State Sankey Diagram Analysis Water Use Terminology for 2010 Data

Agriculture - combines the USGS categories of livestock, irrigation, and aquaculture.

E.2 Energy Use Terminology

E.2.1 SEDS Energy Use Terminology

The following is an abbreviated list of some terms defined in the SEDS glossary:

Barrel (petroleum): A unit of volume equal to 42 U.S. gallons.

Biomass: Organic non-fossil material of biological origin constituting a renewable energy source.

Commercial Sector: An energy-consuming sector that consists of service-providing facilities and equipment of businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. The commercial sector includes institutional living quarters. It also includes sewage treatment facilities. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a wide variety of other equipment. *Note*: This sector includes generators that produce electricity and/or useful thermal output primarily to support the activities of the above-mentioned commercial establishments.

End-Use Sectors: The residential, commercial, industrial, and transportation sectors of the economy.

Industrial Sector: An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity: manufacturing (NAICS codes 31-33); agriculture, forestry, fishing and hunting (NAICS code 11); mining, including oil and natural gas extraction (NAICS code 21); and construction (NAICS code 23). Overall energy use in this sector is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting. Fossil fuels are also used as raw material inputs to manufactured products. *Note:* This sector includes generators that produce electricity and/or useful thermal output primarily to support the above-mentioned industrial activities.

Residential Sector: An energy-consuming sector that consists of living quarters for private households. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances. The residential sector excludes institutional living quarters.

Transportation Sector: An energy-consuming sector that consists of all vehicles whose primary purpose is transporting people and/or goods from one physical location to another. Included are automobiles; trucks; buses; motorcycles; trains, subways, and other rail vehicles; aircraft; and ships, barges, and other waterborne vehicles. Vehicles whose primary purpose is not transportation (e.g., construction cranes and bulldozers, farming vehicles, and warehouse tractors and forklifts) are classified in the sector of their primary use. In this report, natural gas used in the operation of natural gas pipelines is included in the transportation sector.

United States: The 50 states and the District of Columbia. *Note*: The United States has varying degrees of jurisdiction over a number of territories and other political entities outside the 50 states and the District of Columbia, including Puerto Rico, the U.S. Virgin Islands, Guam, American Samoa, Johnston Atoll, Midway Islands, Wake Island, and the Northern Mariana Islands. EIA data programs may include data from some or all of these areas in U.S. totals. For these programs, data products will contain notes explaining the extent of geographic coverage included under the term "United States."

E.2.2 State Sankey Data Analysis Energy Use Terminology for 2010 Data

The energy usage terminology used in the Excel PowerPivot calculations and state-level Sankey diagrams generally follows the SEDS glossary, with a few exceptions.
Energy used to produce ethanol from corn via the dry mill process is included in …

Appendix F: Supplemental State-Level Energy-Water Diagrams

Figure F-1 - Hybrid Energy-Water Sankey Diagram for Alaska at a 2:3 ratio

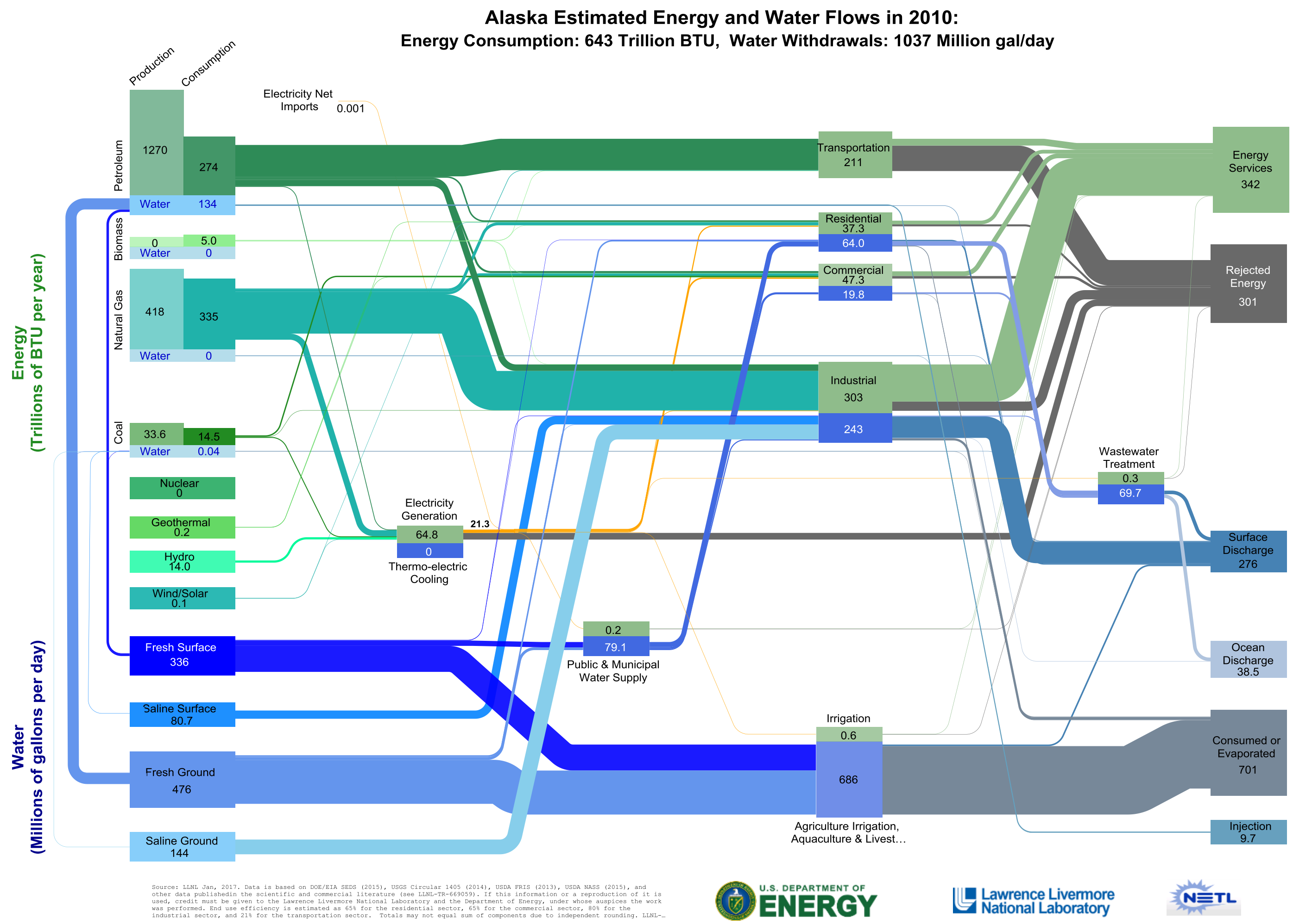


Figure F-2 - Hybrid Energy-Water Sankey Diagram for Idaho at a 1:40 ratio

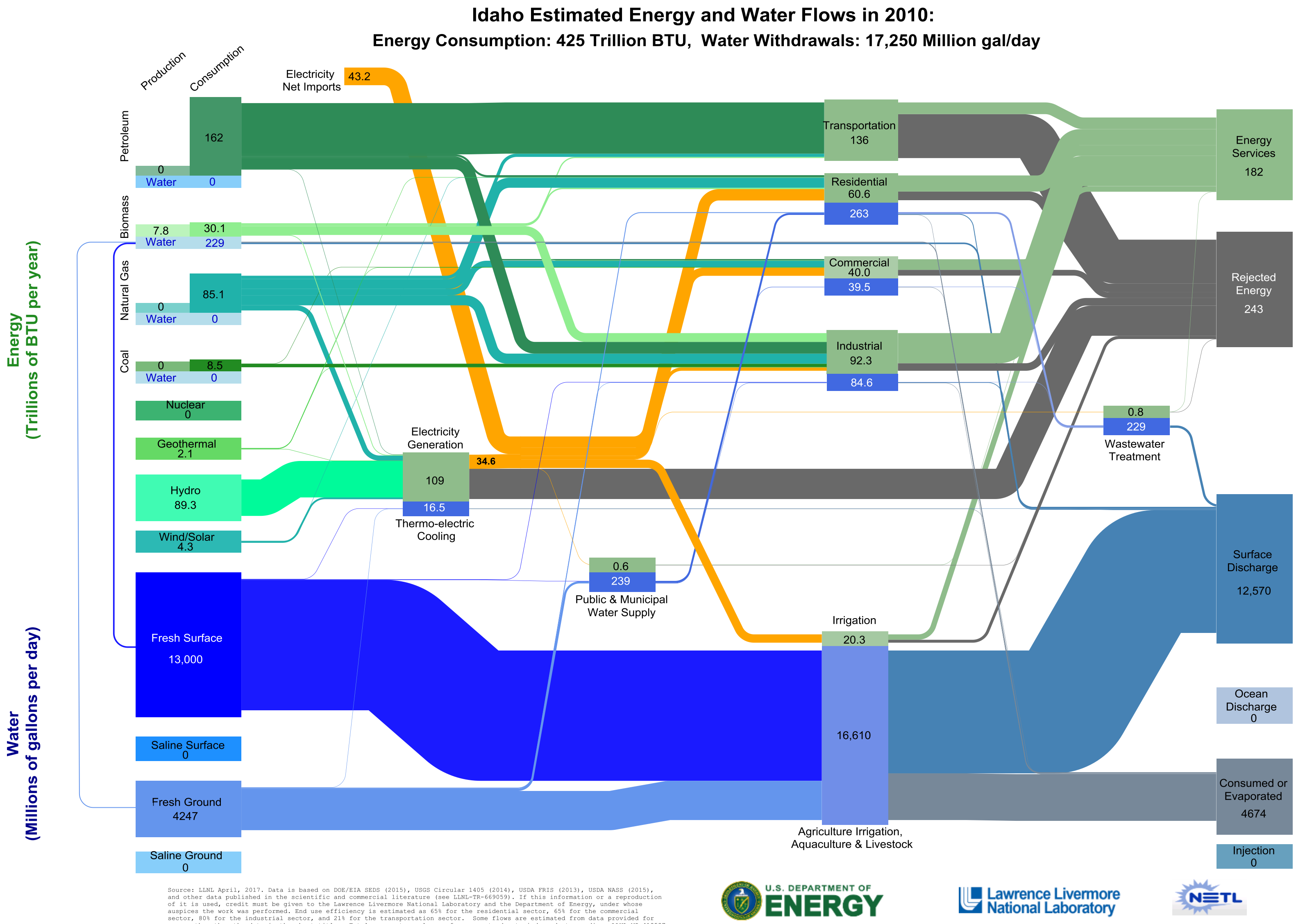
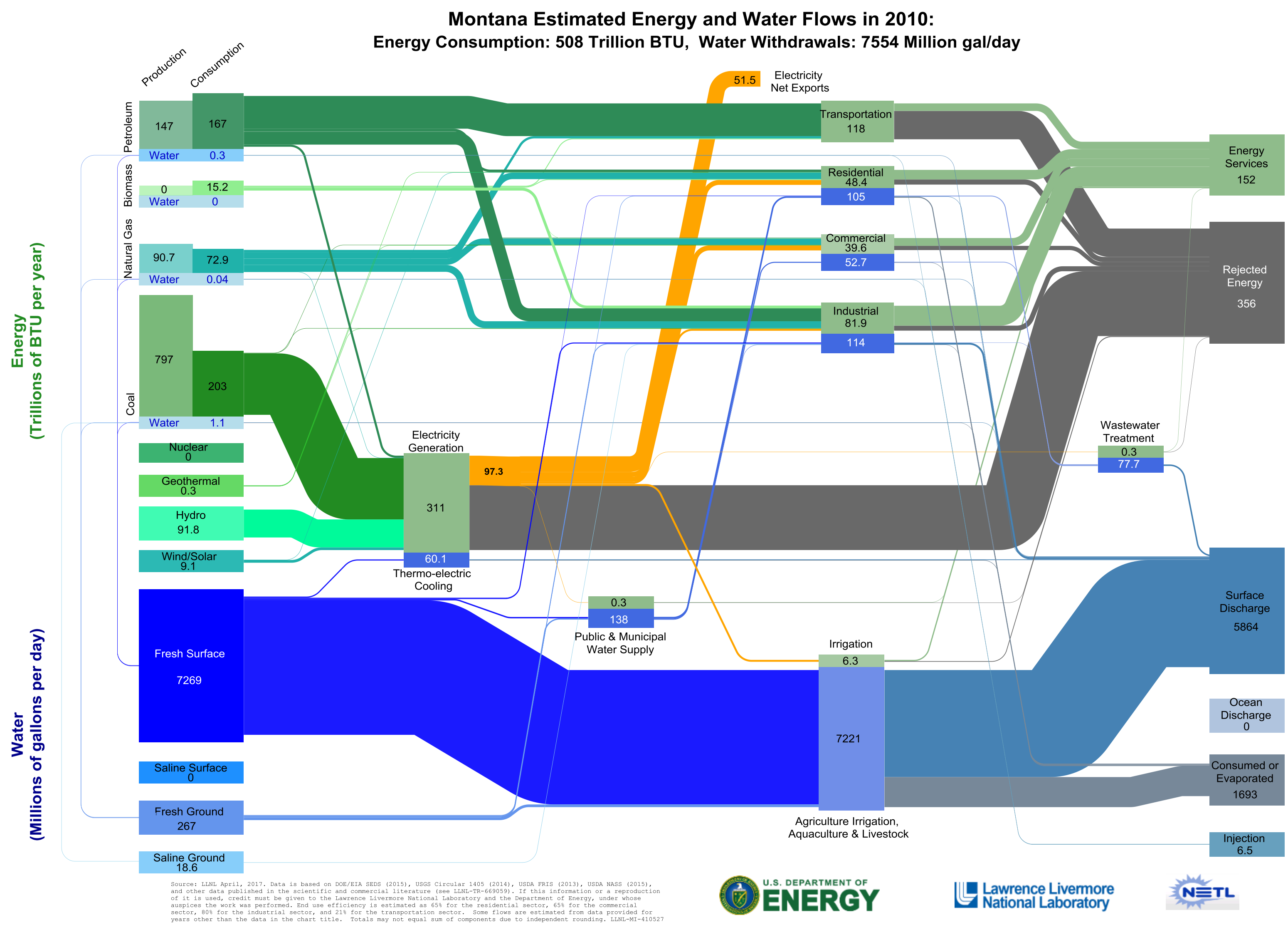


Figure F-3 - Hybrid Energy-Water Sankey Diagram for Montana at a 1:16 ratio



Appendix G: Stakeholder Engagement

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